

**DEVELOPING EDUCATIONAL
GAMES FOR CHILDREN WITH ASC:
VENECA - Virtual Environment for
Navigational Education for Children
with ASC**

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ABSTRACT

This thesis describes the full design process of VENECA, a research tool for experts in the area of cognitive science who specialize in children with ASC. The initial sections of this work concentrate on analyses of open questions and underexplored hypotheses in the area that can potentially be interesting to future expert users, and specifications of interconnected flexible features that could assist experts in their research studies. A review of different deficits of children with ASC, research directions and previous work, done in the area, and critical analysis of analogous computational tools in the area suggested potential problems and doubtful design decisions of the currently existing computer games that had to be avoided VENECA. After that, by means of pre-design analysis, all the constraints and goals of the project were met, and user requirements were specified. As a result, VENECA was developed as a research tool with a game as an internal cognitive element. The design process, which was organised in an iterative fashion, allowed precise specification of all design decisions and adjustment of the system to the needs of both children and research users. Prototype testings with experts in the area provided valuable feedback about not only the experts' requirements, but also those of the child user's. The fact that this feedback was gained during the whole design process allowed for the quick and low-cost fixing of all potential usability problems. At the end of this project, a full scope of initial goals was achieved, and the first version of VENECA was implemented as a complete software package with all necessary manuals and documentation. It provides necessary support for experts in order to answer a set of initial questions. Moreover, flexible combinations of features suggest that experts will potentially be able to specify their own research questions in the future. However, there still exist many directions for future extensions of VENECA, which were also analysed, described and justified in this work.

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To my family, especially to my parents, and friends for their invaluable emotional support
during my Master's studies in Edinburgh.

DECLARATION

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

(Olesya Razuvayevskaya)

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LIST OF ABBREVIATIONS

A list of abbreviations that are frequently used in this thesis is provided below. It does not include specific, not widespread abbreviations, which are explained inside the chapters. All the terms presented in this list are widely accepted in the fields of Cognitive or Computer Science. However, it may be useful for the reader to become familiar with them before proceeding to the next sections.

ASC – Autism Spectrum Condition

ASD – Autism Spectrum Disorder

TD children-Typically Developing children

TTS system – Text-To-Speech system

HCI – Human-Computer Interaction

VE – Virtual Environment

GUI – Graphical User Interface

2D/3D – 2-Dimensional/3-Dimensional

CHAPTER 1

GENERAL INTRODUCTION

1.1 Motivation for implementing a research tool like VENECA

This thesis describes the full process of development of the first version of VENECA – a computational research tool for experts in the area of cognitive science that specialise in investigation of behavioural and cognitive aspects of children with ASC.

Nowadays, there exist a large number of different computational research tools in the area of ASC that are very narrow-oriented. Many applications tend to concentrate separately on gesturing, gazing, emotional education, linguistic skills, etc. While many such applications have recommended themselves as very successful research, educational or therapeutic tools, there exist obvious shortcomings in such a tendency in the area:

- 1) **Economical ineffectiveness.** The development of a separate complicated software, its evaluation and deployment may require several months. Moreover, a well-justified design process usually requires involvement of specialists from different areas: cognitive science, software engineering, graphic design and human-computer interaction. Materials used during the software development may also be costly, for example, specific licensed software may be used during implementation, testing and analysis steps. Taking into account all the time, money and effort costs, it would be much more economical for researchers to have more universal software that could be flexibly adjusted to a separate study.
- 2) **Comparability ineffectiveness.** Quite often, the main goal of a research study is to compare two opposite approaches or to argue a previously existing hypothesis. When talking about computational tools, the existence of different tools in the studies of opposite hypotheses makes such results incomparable with each other. It is always difficult to understand whether the different result is achieved because of the differences in the software tools used by researchers or if the previously existing hypothesis was wrong. Sometimes, even minor changes in the computational environment are able lead to cognitive changes in children with ASC. It would be much more reliable to have unique software that fixes all the features, except those that are directly connected to the hypothesis.

-
- 3) **Cognitive ineffectiveness.** The narrow-oriented research tools usually concentrate on specific difficulties that are presented in isolation from the set of other disturbing factors. Considering the difficulties that children with ASC have with generalization and the complexity of real-world environments, the cognitive progress that the research studies suggest may usually be false. Such an isolation of the difficulties is very risky because in the real world environment there may be many interruptive factors which reduce or absolutely erase the cognitive progress observed in an “idealized” system.
 - 4) **Personalization ineffectiveness.** Children with ASC can demonstrate a large variety of symptoms. These will be discussed in detail in Chapter 2. Moreover, children may have particular personal preferences and interests which are not compatible with the context of the task. Non-flexible tools cannot provide the possibility of adjusting the system to the needs and preferences of a particular target user.
 - 5) **Target ineffectiveness.** As mentioned above, the majority of inflexible games concentrate on particular behavioural aspects in isolation. This creates a potential risk that children with ASC will never use these skills, because there is no explicit target or the situation where such skills can be applied. For example, in the real world, the skill of crossing the road is connected to the more general task of navigation, so presenting these skills in conjunction with each other is more indicative of a real-world situation for child users.

1.2 VENECA - a flexible research tool

Taking into account all the disadvantages of narrow-oriented inflexible computational tools, VENECA was developed as a complicated research tool that is addressed to experts in order to adjust the system to the particular studies and needs of users. VENECA uses a game as an internal cognitive element for the exploration of children’s behaviour.

Throughout this thesis, the word “*users*” will be used in two different meanings: “*expert users*” and “*children users*”. Therefore, it is important to have a clear understanding of what the differences are between these two user groups. When talking about the “*target user group of this project*”, the research users are considered. However, the “*target user group of researchers and their studies*” refers to children with ASC. Child users are considered in this thesis, as potential participants of the researcher’s studies, and as the users of VENECA’s game element. VENECA, as a research tool with a game element,

considers both user groups: researchers and children with ASC. Therefore, throughout this project, both groups of users are analysed in order to ensure that the target group of this project (researchers) will potentially be able to use this tool on the target group of their studies (children with ASC). In this thesis, children with ASC are sometimes also referred to as “*final users of VENECA*”, because they close the chain:



VENECA, as a complicated virtual environment, supports a multitasking approach. At the same time, VENECA includes a main task of the game element: navigation. However, navigation is not the only task that the final users are required to fulfil: it includes many other hidden sub-tasks, such as comprehension of a complex and dynamic environment, crossing the road and understanding the traffic rules, understanding written and verbal instructions, memorizing, using a keyboard and computer mouse, associating abstract objects with real-world objects, and following the gestures and gazes of main characters. Description of all these activities provides information about the variety of tasks that can be hidden in the complicated virtual environments with the main task, and that these may potentially be separately interesting for experts, as research questions. Therefore, it is essential to provide the possibility of turning off some of the activities in order to concentrate on other activities. Additional hidden activities that children are perform during navigation are division and organization of their time and attention between varieties of tasks. In order to explore this activity, experts may require the inclusion of all the activities in the same study.

1.3 Street navigation as the major game task. Motivation and description

As already mentioned, along with the hidden sub-tasks, VENECA includes the main task: navigation in the streets. The aspect that makes this task “main” is the fact that it is present in all the modes and along with all the game features. While previously described activities can be flexibly turned off or optionally included in the study, the navigation task is inflexible, and provides the context for the sub-tasks during the whole playing time.

There are several motivating cognitive reasons for using navigation as a main game task. Unfortunately, the problems that children with ASC can experience during navigation are

very often disregarded because of the evidence that children with ASC have strong visual comprehension. Probably, this is the reason of why currently there is not any computational research tool in the area that concentrates on multi-tasking navigational education in the street. At the same time, street navigation is the sort of task that can be very stressful for autistic children. In their book “Fabric of Autism” (2004), Hutton & Bluestone describe the importance of feeling of safety in space for children with ASC (p 50-51):

“...feeling of lost in unfamiliar space, and needing to know where we are in the surroundings...”

This quote clearly describes the stress that children with ASC experience when navigating the streets. Hutton & Bluestone (2004) also mention that it is important for children with ASC to understand “how to move easily and safely in space”.

Another difficulty that can make navigation difficult is related to motor problems during walking tasks, often observed in children with ASD. Damasio & Maurer (1978) reported about children with ASC who demonstrated walking patterns similar to the behaviour observed in children with Parkinson’s Syndrome (see Bergeson et al (2008) for more details): slow moving speed and small steps.

Navigation is one of the tasks where children with ASC require specific multitasking skills of for dividing their attention and time between finding a location, crossing the road, memorizing information and communicating. Children with ASC have difficulties with all these skills; moreover, absolutely unfamiliar space usually generates a feeling of stress and danger. Therefore, it is very important to help children at the target age adapt to this task, in order to avoid these problems in adulthood. In addition, the fact that navigation is a multitasking activity makes this task an excellent “background context” for exploration of all associated actions that can be flexibly selected by experts.

Considering all the difficulties mentioned above, it is interesting and surprising that evidence shows that, children with ASC enjoy routing games which include small tasks and rewards at particular steps of the path. This creates a great motivation for implementing a computational game with the same logical structure. T. Bushey, a speech language pathologist with more than 12 years of experience of training children with ASC at the Scottish Rite Clinic for Childhood Language Disorders, provides a description of many routing and navigation-based games that are widely used in practice and are

appreciated by children (for further information, visit <https://sites.google.com/site/autismgames>).

1.4 Potential research studies that can be organized by means of VENECA

When selecting a set of flexible features for VENECA, it was important to consider those that are essential for the exploration of “open questions” or underexplored hypotheses in the area. The final version of VENECA is able to assist experts in answering the following questions:

1.4.1 Believability levels and their effect on comprehension and generalization

- To what extent can the levels of believability support the child’s comprehension of the environment?
- Is there a need to introduce those levels iteratively in order to help a child adapt to the real-world task?
- For the navigation task specifically, is the most believable mode the most appropriate teaching environment?

Believability is a very important feature of every computational game, because it assists children with ASC in the generalization of their skills. Believability is defined with a large set of criteria which will be further discussed in the “Design” section of this thesis. Believability defines the ecological validity of the game (see Rizzo & Kim, 2005), which is related to the similarity between the game and the real world and the influence that the game tasks have on the real-world activities of users. When talking about the final target users of VENECA, the question of believability becomes much more important, because of their weak generalization skills. There exists empirical evidence (see Plaisted, 2001 for detailed analysis) that even minor changes in their environments are able to stress the target users. Returning to the cognitive ineffectiveness of narrow-oriented games, as mentioned in section 1.1, it is also directly dependent on the believability of games which tend to isolate the “target task” from a variety of other disturbing tasks that can accompany it in the real world.

However, there exists another aspect when talking about believability and its meaning for children with ASC. Considering the amount of stress that children experience in the real-world tasks, computational games provide the potential to make the environment more

controlled and simplified. Therefore, there is a risk that a highly believable virtual environment will decrease children's comprehension and simulate the same stress that they experience in real life.

The trade-off between these two factors forms a very interesting research question that is currently not explored in the area: "*What is a balance between the optimal generalization and comprehension of the VE?*" One of the most recent critical analyses in the area by Parsons & Cobb (2011) also mentions the crucial importance of this evidence for future research. Therefore, as mentioned, it is essential to investigate to what extent virtual environments' believability can assist children with ASC in their generalization without reducing their comprehension. This question is not currently explored, and the reason is highly related to the fact that there is no any flexible research tool that would allow the variation of the environment's believability. This question cannot be analysed by means of comparison of different systems because factors, such as the difficulty of the task or the number of visual elements make them incomparable. Therefore, VENECA was developed as a first computational game for children with ASD that allows such a variation with the fixed task and number of visual elements.

Moreover, such a flexible tool, can suggest to the experts an absolutely new perspective of the "computer"- "real world" generalization dilemma, which iteratively helps to adapt children to more believable levels. On the top of this adaptation is the real world, as an environment with the highest possible level of believability.

An additional motivation, making the believability question especially interesting to explore, in the context of the navigational task, is that navigation is an example of a task that can potentially suggest the highest optimality of balance between generalization and comprehension. Navigation requires a feeling of moving through space, and making decisions about directions on the basis of visual information that people observe from the real-world 3D scene and different dynamic factors and signals. The less realistic (static and flat) simulations of the environments are not able to provide the full set of this information. Therefore, there exists the probability that children with ASC will demonstrate the highest comprehension in the highest level of believability, which will be the most optimal balance between their generalization and comprehension.

1.4.2 Rewards: different way of presenting social communication

- Will children still experience a negative attitude towards social tasks in the case of a social communication with characters being presented as a reward?
- What is the influence of believability on social rewards?

One of the main problems of children with ASC is their weak understanding of social communication and lack of interest towards social activities. Therefore, many educational virtual environments, such as AS (see Rutten et al, 2003 for details), simulate social situations in order to educate children on how to behave in social situations. In most of these games, characters are not assigned a striking personality: they cannot speak, express motions or perform actions. According to the recent report by Kohls et.al. (2012), children with ASC have approximately the same difficulties in understanding both social and non-social rewards. This evidence forms a good research question of whether the social communication, presented as a reward, is able to improve the attitude of children towards social tasks. However, in order to explore the role of social rewards in social communication, experts might require confirmation of the evidence that social and non-social rewards are equally comprehended by their target users. Therefore, VENECA includes two kinds of rewards: social and non-social, and experts can include either of them in their studies.

In their work, Kohls et.al (2012) have also mentioned that the problem with most of the research studies that concentrate on social rewards might be the fact that they use static photos for social rewards, and that dynamically moving and more interesting characters might be more exciting for children. The levels of believability of VENECA provide a great possibility for exploration of this hypothesis. The experts are able to observe whether the believability of characters presented in social rewards can motivate and engage children with ASC.

1.4.3 Influence of verbal information on the overall comprehension

- Are verbally delivered tasks able to have any positive or negative effect on children's comprehension when accompanying other forms of information (written and graphic)?

While having good visual comprehension and being “visual thinkers” (see Grandin, 1995), children with ASC have always been known as individuals with impaired verbal and written comprehension. At the same time, when comparing the verbal and written comprehension of children with ASC, verbal comprehension is much more impaired. Children with ASC can often be very good readers: their minor problem with reading refers to the pieces of text that require either imagination or inference (see Abisgold, 2007). At the same time, children with ASC usually demonstrate very weak verbal comprehension and are not able to concentrate on the speech of other people. But there is no evidence of whether the verbally presented information affects the comprehension of information which is at the same time delivered in written and visual form. Therefore, the VENECA provides written presentation of all the tasks which is supported with different images and visual cues. At the same time, it includes the verbal representation of the same tasks. Experts are able to select either verbally or visually delivered tasks for their games. They are also able to combine both kinds of task representations in the same game. By means of comparing the children’s comprehension of only written and both written and verbal tasks, experts will be able to understand the importance of verbal information for children with ASC. This evidence may have crucial implications for the development of future games and on the organization of future empirical studies.

1.4.4 Navigation speed

As mentioned in section 1.1, the main advantage of flexible environments is the potential to adjust the game to the particular needs of the user. When talking about navigation, it has already been mentioned that children with ASC sometimes demonstrate motor difficulties, such as slow motion. Therefore, it is important to adjust the navigation speed to the needs of a particular user. This will allow final users to comprehend the environment at a pace that is close to their real-world comprehension.

1.4.5 Visual cues

Another aspect already mentioned is that children with ASC are “visual thinkers”, and usually think in pictures. At the same time, they have weak imagination (one of the factors that make the reading tasks difficult). It would be much easier for a child to remember a “music shop” as a guitar, than to imagine a building with particular features. Depending on the purpose of the experts’ research, they may or may not require such visual cues to be placed on the buildings. At the highest levels of the system’s believability, experts will usually make the task closer to the real-world, and then the visual cues may be deselected,

while on the lowest levels of education, they may provide good cues for children with ASC.

1.4.6 Traffic constraints

Dynamic traffic on the roads is a compulsory attribute for the VE, which concentrates on street navigation and has the purpose of being believable. The task of crossing the road itself is very important for children with ASC, and has been explored in a separate study by Josman et al (2008). It requires a lot of attention, a skill which children with ASC usually lack. Moreover, road crossing is an example of skill, absence of which may be dangerous for children in their real life. In their studies, Josman et al. were also using a 3D environment, which was fully oriented to the road crossing task. However, it is important to include this educational feature in the context of navigation in order to provide a target where the skill may be applied. Therefore, VENECA includes two types of traffic constraints: social and non-social. Both of these might be useful for experts, depending on the purpose of their study. While the non-social constraints are very educative, and display the full set of road crossing rules supported with images, text and verbal presentation, the non-social constraints, including gazing, pointing and gesturing, may be more comprehensive and engaging for children with ASC. At the same time, in order to provide experts with the possibility of concentrating only on the main task and simplifying the environment, the traffic constraints can flexibly be turned off.

1.5 Overview of the project's goals and organization

In this project, the first version of the research tool called VENECA was implemented. The target final users of VENECA are children with ASC between 9 and 14 years old. Returning to the research questions and the main tasks of VENECA, during this project it was possible to find out the optimal and currently unexplored set of questions and game features that are, at the same time, able to assist each other. For example the navigation task may provide evidence about the most optimal balance between believability and comprehension. The believability levels can also affect the comprehension of social rewards. Future researchers might possibly be able to produce even more interesting questions by means of combining different flexible features of the system.

The main goal of this thesis is to develop a potentially usable environment, for both the researchers and the children users. In order to achieve this goal, each step of the

development process requires rigorous analysis: task analysis before launching the design process, analysis of all the design decisions and evaluation of those decisions with the target users of this project: experts, development of the final version of the software along with documentation. All these steps are described in details in this thesis. The task analysis provides an overview of the actions that both groups of users are required to fulfil, and considers possible usability problems. The design sections describe justified design decisions and their importance for both final and expert users. Between different design iterations, it is important to ensure the game's usability by the experts. Therefore, the development process includes three prototype evaluations. In addition to the project users' usability, these evaluations help to understand the final users' requirements from the perspective of expert users. Moreover, the knowledge achieved during evaluation of VENECA with experts helps in analysing of all potential difficulties and additional information that might be helpful for experts in order to adjust the system, and which is included in the manual document of the game. At the end of this project, a critical analysis of VENECA and its potential extensions are presented.

Chapter 2 of this thesis provides literature review and analysis of different deficits, observed in individuals with ASC. In this section, various tendencies and directions of research studies are classified discussed. In addition, the section provides review of computational tool, used in the area of ASC. Moreover, a detailed analysis of three tools that share similarities with VENECA is made at the end of the chapter. Chapter 3 describes the first two steps of development of VENECA: analysis of goals and constraints and task analysis, which form the pre-design stage. Chapter 4 describes the iterative design process and evaluation sessions following each of three prototype iterations. Chapter 5 describes the final set of VENECA's features and the process of development of software documentation. In Chapter 6, the overview of achieved goals is given and possible extensions are analysed. In addition to discussing different extensions of VENECA, different possible directions for every extension are compared in terms of effectiveness and possible challenges. Chapter 7 includes a final summary of the project.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1. What is Autism Spectrum Condition?

Autism Spectrum is a general term that is used in the area of cognitive science in order to describe a large class of conditions referred to as “pervasive developmental disorders” (a term first introduced by the American Psychiatric Association). According to Levy et al (2009), autism spectrum behaviour can in many cases be identified by means of limitations in response time and communication. The authors classify different symptoms in three main groups:

- Socialization deficits
- Communication deficits
- Repetition.

2.1.1. Socialization. Overview of different deficits and studies

Impaired social skills have always been one of the main deficits of individuals with ASC. Many systems that are used for diagnosing autism consider this impairment one of the main symptoms (for example, DSM – III, ICD – 9). There exist many cognitive difficulties in individuals with ASD which result in their weak social skills. According to Levy et al (2009), impairment of social behaviour in autistic individuals refers to three main limitations:

- Absence of particular interests
- Initiation of dialogs with delays
- Absence of any kind of social analysis and judgement.

However, the actual number of social difficulties in people with ASC is much higher than the deficits described by Levy et al (2009). The earliest works in the area of autism were done by Kanner (1943) and Kanner & Eisenberg (1956). They provide a very detailed description of different socialization difficulties that can be observed in autism spectrum. These symptoms include a lack of interest towards social activities, inability to use a language as a communication tool, difficulty in initiating eye contact and a lack of understanding of particular behavioural rules accepted by the society. In addition, according to the authors' specification, individuals with ASC usually have impairments in

their comprehension of other people, which always results in socialization difficulties. These impairments include the tendency to treat other people as inanimate objects and pay more attention to non-social parts of people, such as clothes or other peripheral objects. Moreover, different parts of people's bodies are usually treated by individuals with ASC as separate objects, without any connection to a person. Individuals with ASC also demonstrate difficulties in comprehension of the gestures of other people. In most cases, the overall attention of people with ASC is much higher for inanimate objects than for people, which sometimes results in their withdrawal from society. Another important problem, mentioned by the authors refers to the challenges of individuals with ASD in understanding or guessing feeling of other people. Unlike TD people, people with ASC are usually not able to infer this information from the intonations of speech or emotions of other individuals.

All the difficulties described above create a great barrier between individuals with autism spectrum and other TD people. However, not all of them are necessarily present in every person with ASC. For example, the study by Wing & Gould (1979) reported that not all children with ASD demonstrate withdrawal from other people, and many of them show a willingness to interact with their peers. However, they sometimes experience difficulties in finding an appropriate communicative tactic.

For a long period of time, the avoidance of eye contact has been one of the main social symptoms of peoples with autism spectrum. The majority of earlier studies have supported a theory of "eye-gaze avoidance", first introduced by Hutt & Ounsted (1966), and further supported by Richer (1976) and Castell (1970). All these studies have reported individuals with ASC who had shorter fixation on other individuals' faces than on peripheral objects. Controversial evidence proposed later by O'Connor & Hermelin (1967) suggests that children with ASC have shorter eye fixations not only on faces, but on all objects, compared to those of TD people. This study created a new direction for future research, and analogous results were later reported by other authors (see Davids (1974), Langdell (1978) for details). The question of eye avoidance still remains a controversial aspect in the area of ASD.

A number of research studies have explored the ability of autistic children to imitate other people. An interesting study performed by DeMyer et al. (1972) compared the ability of autistic children to imitate body movements to their imitations of people using objects. The results show that children demonstrated a higher performance in imitation of objects'

usage. In their studies, Uzgiris and Hunt (1975) analysed the imitative abilities of individuals with ASC according to their mental age, and discovered that children of lower mental ages have much weaker imitative skills.

Different research studies have concentrated on face processing patterns of individuals with ASC in order to understand the origins of their deficits in comprehension of emotions and gazes of other people. One of the earliest studies concentrating on face processing patterns of individuals with ASD, made by Langdell (1978), examined the photographic face processing skills of two groups of children, 9 and 14 years old (also the age limits for the final users of VENECA). For both groups of participants, photographs of their classmates were shown on a screen, with particular parts of faces hidden. It was discovered that the participants from the younger age group demonstrated better photographic recognition of their classmates based on the lower parts of faces (mouths), while the older group of participants didn't demonstrate any significant difference in face recognition for upper and lower parts of faces. Another study, which used a similar approach, was performed by Teunisse & Gelder (2003). Unlike Langbell (1978), who defined the differences in face processing depending on the age of the participants, the authors have concentrated on participants' inverting skills. The results demonstrated that individuals with ASD don't have a composite effect, usually observed in TD people. When analysing this result, it becomes obvious that it fully supports the previously mentioned (Kanner & Eisenberg, 1956) tendency of people with ASD to process different parts of other people in isolation, but not in context with each other.

Later studies of face processing patterns of individuals with ASD tend to use more advanced computational eye tracking mechanisms. A series of studies by Klin et al (2002, 2003) investigated the fixation points of TD adults versus the adults with ASC when complicated social scenes with active people characters are presented. When analysing the face processing patterns, it was discovered that people with ASC have a strong tendency to fixate on the lower parts of the faces, while the TD people usually pay more attention to the upper parts of the faces, fixating on the eye regions. While eyes express more social information, the difficulties that people with ASC demonstrate may have a relation to their fixation patterns. Interestingly, this evidence corresponds with the results observed in 9 year old children with ASC, in the study by Langdell (1978) mentioned previously, where participants demonstrated better face recognition when given the lower parts of the photographs. This evidence seems surprising because the older group of children in the

experiment by Langdell (1978) didn't demonstrate any strong bias towards the lower parts of the faces, and it remains unclear how this pattern changes with age. In addition, studies by Klin et al. (2002, 2003) discovered that individuals with ASC tend to focus on peripheral objects presented in the scene even when there is an active person character in front of the scene.

Another group of face processing studies in the area concentrates on left versus right parts of the face. Before the very recent research by Dundas et al. (2011), there existed empirical evidence in the area of the bias of autistic children towards the left side when processing faces, which was reported by several authors (see studies by Butler et al. (2005), Butler and Harvey (2006); Guo et al. (2009) for more details). Another study, by Noris et al. (2011) investigated the exploration of visual fields by children with ASC between 2 and 8 years old. In these experiments, the authors used eye-tracking mechanisms during the playing process. The results demonstrated the phenomenon of the "downcast gaze" – the tendency of children with ASC to fixate their attention on the lower part of the visual field even though the most active objects, such as the researcher's eyes, and toys, were located in the upper part of their field of vision.

Starting from the first work in the area of autism made by Kanner (1943), different studies concentrate on attentional impairments of people with ASD (see Courchesne et al., (1994); Bryson et al. 1990). Even though most of these studies discovered the overall attentional challenges that people with ASC demonstrate for various types of stimuli, it was studies by Dawson & Lewy (1989 a, b) and later by Dawson (1991) which first explored the differences in attention for social and non-social stimuli. The authors reported a hypothesis about specific challenges that children with ASC have when processing a social stimulus because of its unpredictability and complexity. The later study by Dawson et al (1998) reported overall failure to react to all types of stimuli. However, the strictly social stimuli, such as hands clapping, caused more frequent difficulties compared to non-social ones.

The overview of social impairments of individuals with autism demonstrates that although these can change depending on the person's age, the stimuli and the situation, particular difficulties are present during their whole lives. Some social impairments are usually known to be less or more dramatic (face processing compared to social attention). There also exist some social aspects that are up to date known as non-impaired in individuals with ASC. Most of these refer to self-recognition and understanding of self as an

independent object (see series of experiments with mirror reflection for more details: Flannery, (1976); Ferrari & Matthews, (1983); Spiker & Ricks, (1984); Dawson & McKissick, (1984); Baron-Cohen, (1985)). However, the overall variety of existing challenges describes a high degree of social difficulties in individuals with ASC.

2.1.2. Communication. Overview of different deficits and studies

Although, sometimes analysed along with social difficulties (because speech forms a part of social communication; see “pragmatics” definition further in this section), communication challenges of individuals with ASC refer to their linguistic impairments and inability to comprehend speech. As highlighted by Wilkinson (1998), language difficulties in individuals with ASD may vary highly, from the absence of functional speech to very strong syntactic capabilities. Levy et al (2009) mention two main communication deficits observed in the autism spectrum:

- delayed comprehension of speech when no non-verbal elements are presented
- repetitive, impaired or stereotyped speech

In the area of autism, the term “*pragmatics*” is very widely used in order to identify a class of linguistic difficulties which refer to social communication. Considering the variety of social challenges described in the previous section, it is unsurprising that people with ASD have weak comprehension of speech. Pragmatics usually includes a variety of social aspects, such as gazing, gesturing and emotional expressions. The existence of both verbal and non-verbal elements in pragmatics makes speech comprehension in people with ASC more difficult. Two of these non-verbal elements, gesturing and gazing, have received much attention by researchers. A valuable study by Mundy et al., (1986) has identified that the processing of gazes and gestures, taken separately from a communicative context, is not sufficient to identify a child with ASC. Autistic behaviour can only be identified when the non-verbal pragmatics are presented during communication. Moreover, further research has discovered that not all types of communication are able to lead to impaired processing of non-verbal pragmatics. In cases where communication is based on face-to-face social aspects, individuals do not usually show any impairment in comprehension of gazes and gestures. However, when communication involves processing of both the surrounding environment and the partner, people with ASC demonstrate difficulties. This phenomenon is known as impaired “joint attention” (for details, see Lewy & Dawson,

1992; Macarthur & Adamson, 1996; Wetherby, 1986). Joint attention is widely used in the area as one of the main criteria for monitoring people with ASC.

Returning to the repetition, the second symptom, mentioned by Levy et al (2009), this can usually be observed during different types of communication which refer to verbal conversation. Individuals with ASD usually tend to add very little information to the overall context of dialogues, and sometimes have difficulties understanding the ideas of their conversation partners (see Loveland et al., 1990; Paul & Cohen, 1984; Tager-Flusberg & Anderson, 1991). Quite often, people with ASC also produce repetitive words during such conversations (Prizant & Rydell, 1993). The latter phenomenon has received a scientific definition of “echolalia”.

In addition to the previously described groups of communication deficits, a separate class of symptoms refers to specific semantic patterns observed in individuals with ASD. A tendency to use words which are not related or not appropriate for the current context or new, non-existing words, can usually be observed in autism spectrum (see Prizant & Rydell, 1993; Prizant et al., 1997). Moreover, individuals with ASC may sometimes have delayed acquisition of vocabulary, which is in many cases related to their problems with joint attention at early ages (Lord et al., 1994).

A separate class of communication difficulties observed during autism refers to phonologic capabilities. Quite often, people with ASD have specific prosodic patterns which refer to unusual intonations in speech, stress of inappropriate parts of words or sentences, unusual speaking paces and rhythms (Fay & Schuler, 1980, Lord & Paul, 1997). These phonologic difficulties also have a relation to repetitive speech, mentioned earlier. Very often, when repeating phrases, individuals with ASD change their intonations (for example, pronouncing a question in a form of statement), which are more appropriate to the new context (Paccia & Curcio, 1982; Prizant, 1983). This evidence suggests the complex nature of the repetitive speech phenomenon.

Even though not highly impaired, syntactic comprehension of people with ASC also reveals some interesting phenomena. Sometimes, a phenomenon, known as “pronoun reversal” can be observed in autism. For example, when talking about him or herself, an individual with ASC can use other inappropriate pronouns, such as “you”. This observation, first mentioned by Kanner (1943), was reported in several later studies (see Bartak et al., 1975; Lord et al., 1994). Currently, the origins of such patterns are not clear.

A study by Tager-Flusberg in 1994 showed that the patterns don't lie in grammatical difficulties, because participants with ASC could use and recognize more complex possession forms of pronouns ("my") without any errors.

This overview of different classes of communication deficits provides information about a variety of different phonologic, semantic, syntactic, non-verbal and repetitive limitations that individuals with ASC can experience. Some of these have a direct relation to the social deficits, and are very well explored (for example, joint attention), while the nature of other phenomena remains unclear (for example, "pronoun reversal").

2.1.3. Repetition. Overview of different deficits and studies

While one of the repetitive patterns, echolalia, has already been mentioned, people with ASD quite often demonstrate a number of other repetitive symptoms which are not related to speech. According to Gordon (2000), different factors that interfere with these repetitive actions or "rituals" tend to make individuals with ASD aggressive or anxious. In their categorization of different repetitive patterns, Levy et al (2009) highlight the following behavioural phenomena:

- strong interest in only particular topics and apathy towards other tasks
- tendency to perform monotonous tasks
- stereotyped judgement of different situations or views

Other studies tried to classify the repetitive behavioural patterns observed in individuals with ASD. In their study, Lam and Aman (2007) classified different repetitive factors based on the previously existing scale RBS-R (Repetitive Behavior Scale-Revised), introduced by Bodfish et al (2000). The authors could identify five distinct repetitive patterns, which they classified as compulsory, restricted, stereotypic, self-injurious and ritualistic behaviours. A number of subsequent studies in repetitive behaviour (Cuccaro et al., 2003; Shao et al., 2003; Bishop, Richler, & Lord, 2006, Szatmari et al., 2006) have also identified some repetitive classes, according to different scales. The majority of these divide the symptoms into "lower order", which refer to motor repetitions, and "higher order", which refers to cognitive insistence on sameness (IS). A study by Hus et al. (2007) demonstrated that, unlike other repetitive elements, IS is not dependent on the age and level of mental development.

In a later study by Lam et al (2008), three main factors of repetitive behaviour were identified. The class called “repetitive motor behaviours” included different motor criteria, such as repetitive use of other objects, repetitive body movements and hand/finger movements as a specific type of body movement. Another class of repetitions identified by the authors is called “insistence on sameness”, which covers the situations where individuals demonstrated anxiety towards even small changes in the surrounding environments, inability to comprehend these changes, and attempts to resist them. When analysing this repetitive pattern, it is possible to notice its direct influence on generalization difficulties often observed in people with ASD (see Plaisted, 2001). Insistence on sameness, usually observed in autism, often prevents individuals from generalizing their knowledge acquired in a particular environment to other environments, even in cases where the differences between them are not significant. The tendency to have rituals and compulsory activities also refers to this category. The third category, “circumscribed interests”, refers to the tendency to focus on particular objects, topics or activities, ignoring alternatives.

2.2. CHILDREN WITH ASC. MOTIVATION FOR EARLY DETECTION

The first sentence of this chapter describes the spectrum as a class of pervasive developmental disorders. The purpose of this section is to highlight an aspect that makes ASC a “developmental” disorder and clarify the significance of therapeutic techniques at the earliest stages of development.

Some challenges in the communication and socialization of children with ASC can be detected at a very early stage of development, and it is very important to use different therapies to help small children to avoid these challenges, because future development of language and motor skills can be directly affected by these initial deficits. According to Charman & Stone (2006), the American Psychological Association identified two deficits that can be detected during the first year of life in individuals with ASC: inability to follow and initiate joint attention, already mentioned in previous sections, and inability to understand gestures, described in section 2.1.2. The authors also suggest that different methods can help parents in motivating children to initiate joint attention, such as imitating small children, and expressing explicit emotions about their attention focuses (“developmental responses”) and following them. These methods can teach children about the emotions and feelings of other people, increase their eye contact and decrease their

apathy towards communication. Sometimes, verbal responses of small children can be modelled by means of different guiding techniques, such as use of leading questions.

A later study by Siller and Sigman (2002) showed that the level at which children can synchronize with their parents in attention focus at the infant age can predict their language development up to 16 years old. Recalling section 2.1.2 and “pragmatics” which form a part of communication, it becomes clear that challenges with joint attention and gesturing may lead to late language development in individuals with ASC. The semantic deficits related to delayed vocabulary are connected by Lord et al., 1994 to early difficulties with joint attention in children with ASC. Analogous observations were reported by a number of other researchers (see Carpenter et al., 1998, Mundy and Gomes, 1998; Mundy et al., 1990). Moreover, the inability to follow joint attention and understand the emotions of other people can lead to further difficulties in socialization.

In many cases, different autistic patterns are known to be age-dependent (already mentioned differences in face processing in 9 and 14 year old children, reported by Langdell (1978)). For example, unlike social difficulties, repetitive behaviour in children with ASC is not detected at the early stages of development. The average age when repetitive patterns can be observed is 2-4 years old (see Cox et al., 1999; Lord, 1995; Moore and Goodson, 2003). Schultz (2005) mentions an interesting idea about the dependency between earlier social deficits and subsequent repetitive behaviour. Depending on the stress that children experience in social situations during the earliest stages of development, the author assumes that repetition of actions may initially occur as a “compensatory reaction” and then evolve into behavioural pattern.

This analysis helps the understanding of the importance of the earliest therapies of the autism spectrum. None of the challenges observed at the early stages of development disappear in adulthood, and some may lead to more serious difficulties. Different educative methodologies are therefore developing and being practiced in the area of ASC. A large class of such methods, related to computer-assisted therapies and monitoring, is described in the following section.

2.3. COMPUTER TECHNOLOGY AND ASC

During the last decades, the computational approach has received wide popularity in monitoring, educating and treating children with ASC. Considering the various social

barriers of children with ASC, there exist obvious advantages of using computational games for these purposes.

Compared to the unpredictable real-world environment, computer games look much more controlled. Moreover they allow the overcoming of social communication, which is usually a stressful activity for children with ASD. In addition, compared with sometimes unclear and implicit social stimuli, computational games provide a unique possibility of making these stimuli more explicit, interesting and strong. For example, different colourful animations, interesting characters, sounds and video are able to engage children. Some games allow a high degree of personalization and adaptation to the particular need of the user. The possibility to adjust the level of difficulty to a particular user is sometimes very important for educational purposes. Moreover, computational games allow avoidance of potentially stressful aspects of the real world, which generates a feeling of safety in child users. The real world environments don't allow such a unique possibility of personalization, simplification and control.

Moreover, computational technology has an irreplaceable significance for research studies which try to understand the world from the perspective of children with ASC. For example, already mentioned studies by Klin et al (2002 a, b) that used eye tracking mechanisms suggested more reliable results than the previously existing studies using hidden parts of photographic faces.

There exist a large variety of games in the area that concentrate on particular challenges of children with ASC. When analysing the full scope of all these games, it becomes possible to classify them into different groups based on general goals. This chapter will describe three main classes of computational games that have received high popularity in the area and some examples of such games.

2.3.1. Linguistic computational tools

As becomes clear from section 2.1.2, language development is one of the main criteria of normal communication in individuals with ASC. Challenges in non-verbal communication usually cause delays in vocabulary comprehension. Therefore, various computational games concentrate on the language education of individuals with ASC. This section provides more detailed analysis of different linguistic educational programs for children with ASC, from simplified complicated computational to more complicated ones.

An interesting study performed by Moore et al (2000) examined the importance of computer software in teaching vocabulary. Its significance is based on the fact that the authors not only used a computer-based technology in order to teach vocabulary, but also compared the results with those of the same educational program that had been presented by teachers. Both educational programs included the same technique of asking child participants to select different items when the name of the item is produced. For both methods, the authors also used specific guiding sentences, delivered in a verbal form, until the child correctly selected an item. The only difference between these methodologies was the fact that computational software also included interesting sounds and animations of objects. The results of Moore et al.'s (2000) study demonstrated a much higher degree of attention and motivation in children with ASC when the items were presented by the computer software. Moreover, the proportion of words learned during this experiment was much higher in cases where they were delivered by the computer software. This evidence highlights the importance of computer technology in order to make the stimuli stronger, as mentioned earlier.

Another linguistic software was used by Heimann et al (1995) in order to educate children with ASC. The authors used a program called Alpha, which is much more comprehensive, since it includes stronger stimuli, supported with characters and videos. Moreover, it presents visualizations of all the sentences by means of displaying corresponding animations. For visually thinking children with ASC, such an approach is a very comprehensive way of understanding information. Moreover, returning to the “target ineffectiveness” mentioned at the beginning of Chapter 1, language acquisition by means of sentences rather than separate words is a more effective methodology because it provides a context where separate words can be used. The results of using the Alpha program demonstrated that children with ASC improved their phonological and reading skills. Moreover, animations were shown to generate a significant degree of interest and enjoyment in participants with ASC.

The language acquisition program used by Bosseler & Massaro (2003) [102], is based on a virtual tutor. The software includes Baldi (see Figure 1), a talking 3D head which delivers vocabulary information by means of various modalities, such as emotions, text and animated pictures. Baldi was also able to comprehend the verbal responses of the users. The authors could detect that the animated human-like head was highly enjoyed by children; moreover, the participants (children between 9 and 12 years old) could produce

more words after using this program. The authors also monitored the result a month after using the software, and discovered that 85% of new words were still remembered by children with ASC.

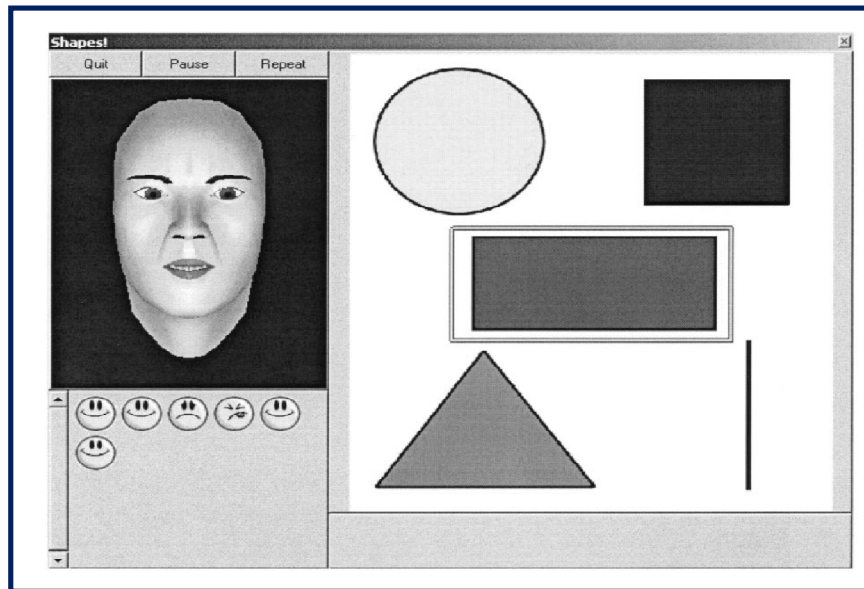


Figure 1. Prototypical version of Baldi used in Bosseler & Massaro's experiment (2003)

Another study, by Hetzroni & Tannous (2004), provides even more contextual information by means of presenting sentences that are appropriate for a particular situation and verbally guiding users. This approach avoids the target difficulties described in Section 1.1. Moreover, the software used in the studies by Hetzroni & Tannous (2004) also provides a good degree of personalization (also mentioned in section 1.1), wherein users are allowed to select an environment and situation of their preference. Such an approach reduces the risk that children with ASC will never use their skills in real-world tasks, because they are already suggested in an appropriate context. Additionally, the teachers using this software in their classrooms reported a reduced “echolalia” effect, (as described in section 2.1.2).

2.3.2 Computational tools which teach emotions

Starting from the first publication about autism, by Kanner (1943), emotional recognition has been treated by researchers as one of the main challenges that prevent normal social development by children with ASC. As highlighted by Charman & Stone (2006) children with ASC enjoy education which is based on explicit trial and error. While emotional recognition requires observational techniques and cannot be learned through trials, children with ASC experience specific difficulties in understanding emotions. Therefore, several computational tools were designed in order to teach children emotions by means of trial

and error based methodology. This chapter covers some of these games starting with the more simplified ones.

Bolte et al. (2002), used software in their studies with a large collection of photographs of emotions. The photographs were presented in the form of static pictures, and children had to recognize emotion based on the photograph. After the response was given, the children received feedback explaining the meaning of this emotion, and an animation of the emotion was presented as a reward. Two groups of children were included in the study; one group received computer based and another one received non-computer based trials. The group which was trained by means of the computer software demonstrated high improvement in their recognition of emotions. However, another challenge that was noticed in this experiment is that these improvements were observed only as long as the stimuli were presented in an environmental context. Children failed to generalize their emotional recognition skills to other environments. This result highlights the importance of considering “cognitive ineffectiveness” as mentioned in section 1.1.

A similar study by Silver & Oakes (2001) also uses software for emotional education. The software, called Emotional Trainer (Figure 2), includes both static photographs and animated emotions of people. Different types of guiding sentences and rewards were also presented depending on the correctness of the users’ responses. The authors used not only explicit questions about the feelings of people on the pictures, but also provided different sentences, and asked children to infer what led to an emotion displayed on the picture, or how the person feels about a particular situation.

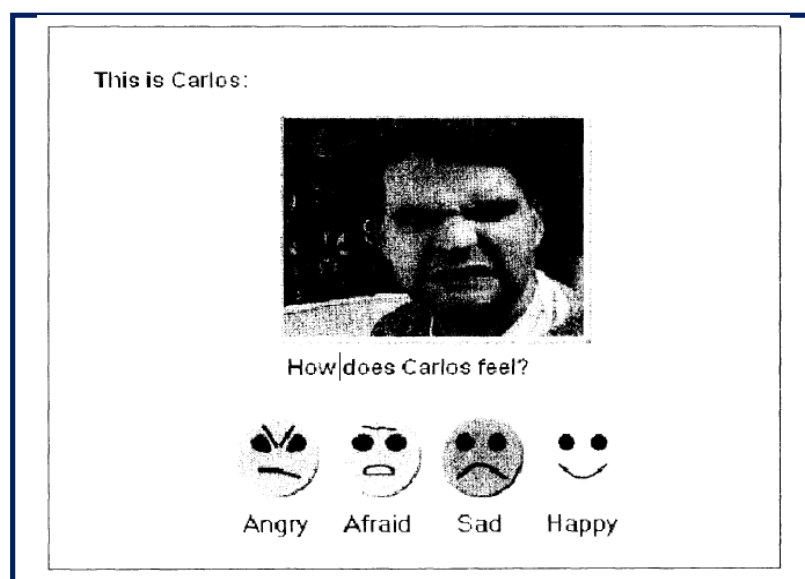


Figure 2. Emotional Trainer used in study by Silver & Oakes (2001)

2.3.3 Computation tools used for social education

Compared to the previous, more specialized, games, social educative tools allow the teaching of children within a more general, real-world, context. Such games usually teach users about behavioural patterns accepted in society for a particular situation. Another important feature of such games is that they usually include a corresponding context as a background for a particular social situation, which reduces generalization requirements in order to transfer skills into real life.

One such game was used in studies by Bernard-Opitz et al (2001). The software presents some difficult and conflicting social situations and requires users to make particular social decisions in order to resolve a conflict. Such decisions are very motivating for the increase of social judgement, one of the social deficits mentioned by Levy et al (2009). The social environment itself included animation, visual stimuli and recorded speech. Even though the authors did not evaluate the ability of users with ASC to generalize their social solutions to other situations and contexts, the users did demonstrate particular skills in making social decisions. Compared to the TD users, the authors could also observe that users with ASC produced much less novel decisions. This result is not surprising, considering their tendency to monotonous tasks and repetitive behaviour.

Another program, used by Whalen et al. (2006), called Teach Town, uses different complicated stimuli, including speech and social situations. As in the previous game, different animations and visual support are used to motivate users. The social understanding, attention, language skills, memory, and verbal comprehension included in this computational game make it much less narrow-oriented than the previously described tools.

2.4. VIRTUAL ENVIRONMENTS AS MORE APPROPRIATE EDUCATIVE TOOLS

All the types of computational games described above can be virtual environments or not. For example, the studies by Bernard-Opitz et al (2001) and Whalen et al. (2006) are virtual environments since they provide stimuli within the background, while the tools used for emotional recognition provide stimuli in isolation from the environment. This is the main reason for the absent generalization observed in Bolte et al.'s experiment (2002), when children failed to guess emotions once the context has changed.

VEs can be presented as either 3D or 2D programs. The main aspect that makes a game a VE is the presence of particular context in the scene. Rutten et al, (2003) also classify VEs into environments with a single user, and those with multiple users. Unlike environments with single users, environments with multiple users allow different geographically isolated individuals to communicate with each other by means of a common computational tool. This makes the system's responses less controlled and more dependent on the partner user.

Different authors have investigated the positive impact of such environments on children with ASC. Trepagnier (1999) concludes that virtual environments may have a very positive impact on children with ASC because they help them to plan, solve social problems, and communicate. Rizzo and Kim (2005) proposed different features that make virtual environments useful for children with ASC, such as predictability and control, the potential to learn without errors, the potential to self-explore an environment, the existence of different game motivations to complete a particular task, and the potential to receive immediate feedback about actions and decisions. Parsons, Mitchell, & Leonard (2005) also suggested some features that may make these programs helpful for children with ASC, including the possibility of creating social interaction without face-to-face interaction (by means of virtual characters) and the existence of potentially real situations that can occur in real life.

2.5 CRITICAL ANALYSIS OF VIRTUAL ENVIRONMENTS THAT SHARE SIMILARITIES WITH VENECA

This section provides descriptions of some VEs that have similarities with VENECA in one or more aspects, and critically analyses these. For these analyses, three different computational games were selected. All three games described in this section are 3D VEs that have been used in different studies with individuals with ASC.

The first VE was used by Josman et al. (2008) in their road crossing educational study with children with ASC. The target user group of this environment were children with ASC between 8 and 12 years old. The 3D VE that was used by the authors (Figure 3) represents a 3D road with a traffic light that displays both vehicles' and pedestrians' signals. One aspect which makes this study important is that it has high ecological validity in terms of the importance of road crossing skills in real life. Moreover, this study not only examined cognitive aspects during the game playing process, but also included monitoring which

helped to understand the generalization effect. The authors used videotaping to monitor all six participants, and observed that half of them improved their behaviour on the road.

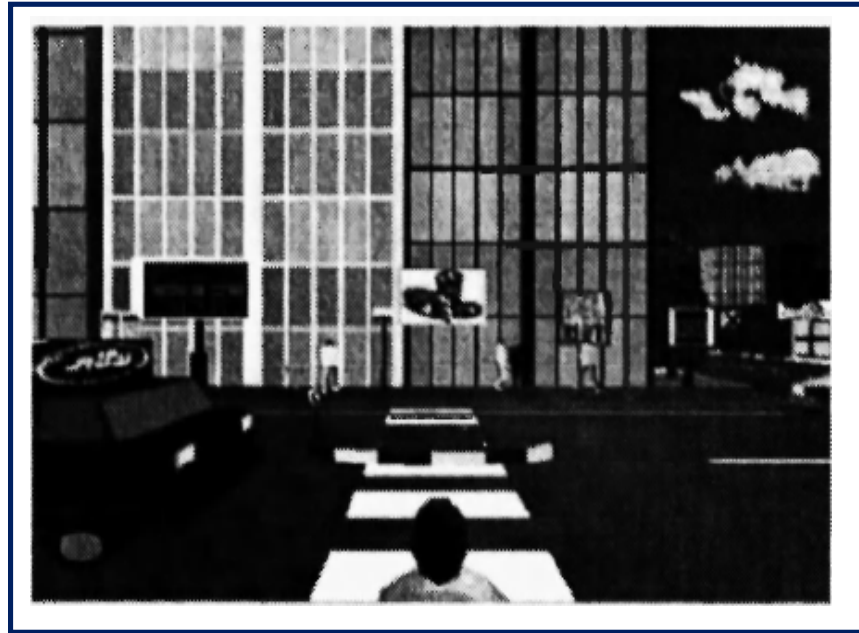


Figure 3. VE used in Josman et al.'s road crossing task (2008)

Since the navigation principles used by Josman et al (2008) are very close to those behind the purpose of VENECA, it suggests the possible age of final target users that will be able to succeed in their task.

There are two important points to mention when analysing the software used by Josman et al (2008). First of all, the road crossing task has a good ecological validity from both the similarity of the scene to the real world and its potential importance for children with ASC who have limitations in their attention. At the same time, the context in which the road crossing task is presented could be wider. It would be much more effective for generalization purposes to introduce it in context with a more global navigation task. One of the design decisions that also looks questionable is the system's response to the user's attempt to cross the road in an inappropriate time. The system displayed a vehicle's braking sound and a sign of an accident on the screen. While, one of the advantages of computational tools is the ability to reduce real-life stress and danger and make the environment more controlled, an attempt by developers to imitate an accident may be stressful for children with ASC. It could be much more educative if the system displayed an educational message instead, or at least used less stressful stimuli.

The second environment with potential similarities to VENECA was used by Rutten et al.(2003). The environment suggests two possible scenes: a café and a bus (Figure 4, a, b). It is a fully social environment which educates children of how to behave in social situations.

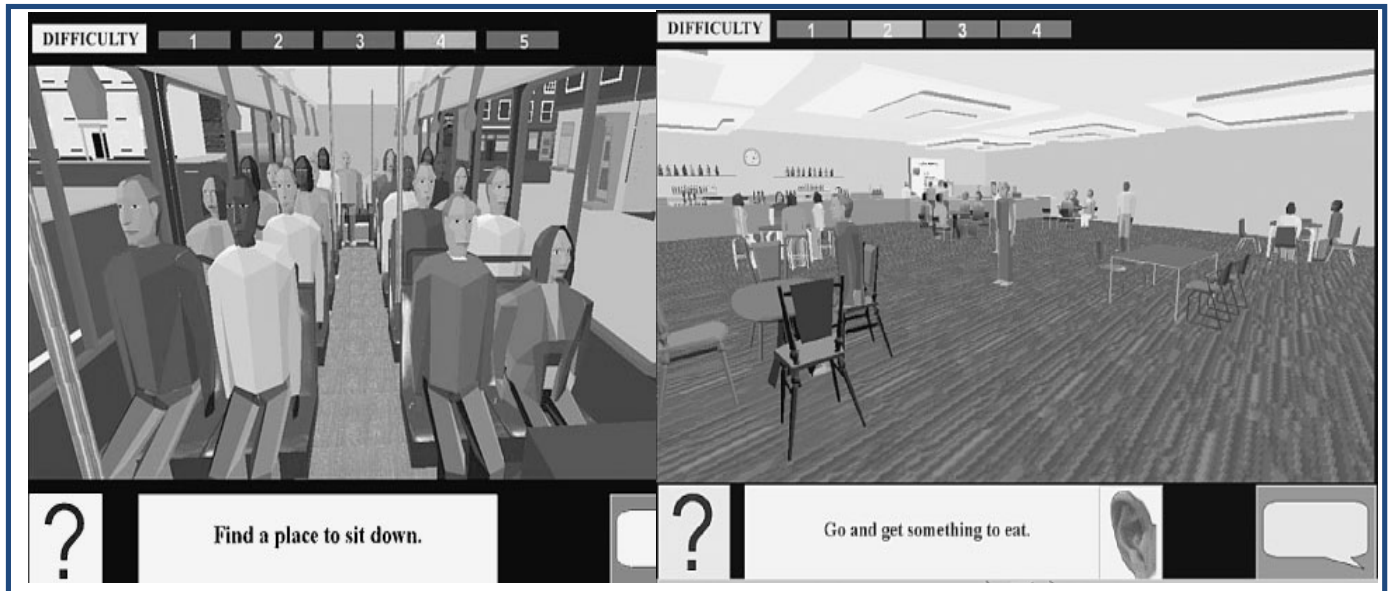


Figure 4. VE used in study by Rutten et al (2003) (Left: bus scene, right: café scene)

The environment also has a high ecological validity, because all the situations simulated by the software are real-world situations. The idea of introducing different levels of difficulty also suggests a particular degree of flexibility. Some potential shortcomings of the software may refer to believability aspects. While the 3D scenes look believable enough, the textures and the characters have been simplified. Moreover, the characters used in the scene are not assigned an explicit personality, which can affect believability. The decision to introduce the task without any “story” inside the game, could also affect the engagement of child users.

The third VE was used in Rajendran et al.’s (2011) study on the multitasking skills of adolescents with ASC. The principal factor that makes this environment similar to VENECA is that it also supports multitasking and highlights its importance for individuals with ASC. VET (Figure 5), the environment that was used in the authors’ study, has a main task which is close to VENECA’s and is based on navigation. This fact once more highlights the importance of presenting navigation as a multitasking activity. In addition, VET is the first of three described systems which presents the task in the context of a story. However, when talking about the environment of VET, it has some potential differences

from VENECA. First of all, in its ecological validity, the scene used in the VET is more simplified and represents a university building with three levels. Moreover, in order to focus on multitasking rather than on navigation, the authors have limited the time of participants using a timer and motivated them to increase the pace. While providing good evidence about challenges that adolescents with ASC may have with time division and multitasking, this method may not be appropriate for educational purposes. This timer may have a stressful influence on participants in cases when the task is not accomplished. Moreover, while the navigation in VENECA is absolutely flexible, the criteria that the authors in Rajendran et al.'s (2011) study were using in order to identify the optimal time that is considered a norm remains unclear.



Figure 5. VET, VE used in Rajendran et al.'s (2011) study

The following table provides a comparison between the systems described in this discussion, based on different criteria.

Criterion	Josman et al (2008)	Rutten et al. (2003)	VET, Rajendran et al.'s (2011)
Believability	High	Simplified scene	Simplified scene
Potentially stressful stimuli exist	Yes (accident simulation)	No	Yes (limited time)
Other characters appear	No	Yes	No
Believability of characters	-	Low, no emotions and personalization	-
Navigation is used	Yes	Yes	Yes
Degree of flexibility	No	Flexible levels of difficulty	No
Tasks' representation	No specific instructions, automatic proceeding	Written on the screen	Written on paper
Individual needs of users considered	No	No	No
Story provided	No	No	Yes

Table 1. Comparison between three VEs: Josman et al (2008), Rutten et al. (2003), VET, Rajendran et al.'s (2011)

Analysis of these environments helped to avoid analogous difficulties in VENECA. For example, it might be useful to consider levels of difficulties and implement explicit instructions, while potentially stressful signals must be avoided. Moreover, analysis of the whole scope of problems, presented in this section allowed defining potential user requirements that must be considered during the design stage, which will be discussed in the next section.

CHAPTER 3

PRE-DESIGN STEPS

VENECA was developed on the base of the classical waterfall model (Figure 6) (Dix et al, 2004, pp 195-196). It suggests the optimal and least costly method of software development that allows elimination of all potentially conflicting or unusable design decisions at the earliest steps of analysis, before the design process is launched.

This chapter covers the first two steps of the project that form the pre-design stage:

- 1) analysis of the goals;
- 2) task analysis.

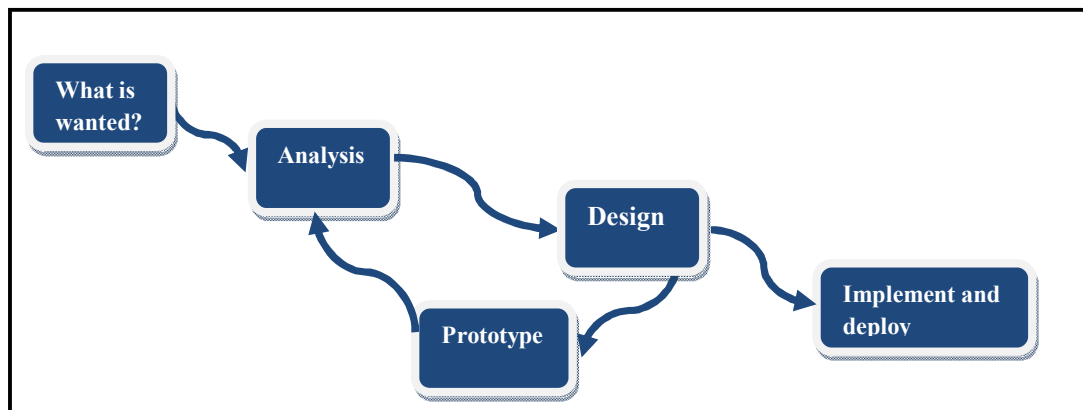


Figure 6. Waterfall model for interaction design process (Dix et al, 2004)

3.1 PRE-DESIGN STAGE. WHAT IS WANTED?

In accordance with the classic principle of software design (Dix et al, 2004, pp 195-196), the first step of this project was the analysis of all the goals and constraints. This stage is crucial for the implementation of well-designed software, because it helps to analyse all the possible constraints that can affect the achievement of initial goals. The ideal design strategy must find a good balance between all potential goals and constraints.

3.3.1. GOALS

At the first stage of the project, a number of software elements that are important for achievement of initial goals were summarised. This sub-section represents the initial set of elements of VENECA. Some of these required further modification as a result of trade-off between the possible constraints and goals.

During the analysis stage, it was decided to implement the following set features in VENECA:

- 1) **Levels of believability:** In order to find out the answers to all the questions concerning believability, specified in Chapter 1, the experts might require a strong technical support that allows variation of believability levels. Therefore, it was decided to implement a game with different levels of environment believability. At the highest level of the system's believability, it was planned to have a 3D environment, with believable textures, dynamic objects and characters. At the medium level of believability of the system, two out of these three variables had to be substituted with the less believable ones: the 3D scene had to be changed into 2D space, and dynamic objects had to be assigned static features. The lowest level of the system's believability was supposed to substitute the third variable of the medium level, textures, with less believable, cartoon-like, textures.
- 2) **Tasks:** In order to help experts in answering questions concerning the importance of verbal information for comprehension levels of children with ASC, it was planned to deliver the tasks in two main forms: verbal and visual. The visual form was planned as a plain text with accompanying images. The verbal representation was planned as a synthesized speech that would produce the same information.
- 3) **Social rewards:** When analysing the problem of social rewards, it was important to identify the set of features that would be included as social rewards. Initially, it was decided that a character would appear on screen, and communicate with the user by means of pointing, gesturing and speaking. The same characters were planned as 2D static objects for less believable modes.
- 4) **Control panel:** In order to provide research experts with a usable interface for changing all these game variables before the game is launched, it was planned to implement a control panel with intuitively presented game variables and a brief description of each game feature.

3.1.2. CONSTRAINTS

The initial idea behind VENECA included four main goals, and it was important to analyse, which of them could be achieved, and to consider all the constraints. The golden rule of the software design states: "*understand your materials*" (Dix et al, 2004, p 193). For every design process, materials can be strictly divided into two categories:

-
- people (users);
 - computers.

Each of these materials may have a large number of constraints, and they have to be considered before the design process is launched.

- 1) **Users:** It was important to analyse, who the users of this software would be. VENECA was planned as a research tool for experts. However, the usability of the tool by the experts is directly related to its usability by children users. Therefore, it was important to define the most appropriate target age for the children users, considering the difficulty of all the tasks. Additionally, there existed a probability that children with ASC may have particular personal requirements concerning the navigation speed and the complexity of tasks. These constraints must be considered in order to make the game usable by experts;
- 2) **Computers:** Implementation of 3D games requires a specific kind of software that allows the modelling of 3D objects. It is essential to analyse what kind of software will be used at this stage. If the modelling software is platform-dependent, this may create problems for future users. It is also important to analyse, in which format the final game will be saved. If the saving format can be only launched by means of specific programs, the experts' usability would become limited. Furthermore, all the objects in the game must support game logic. This will require programming capabilities. If the 3D software does not support integrated programming language, additional tools and knowledge will be required in order to export 3D objects into the programming environment.
- 3) **Timeframes:** given the period of three month (duration of the project), there were several goals to be achieved:
 - Development of the software with very complicated computer graphics. This might require some time for learning of additional artistic, architectural, sculpturing and modelling basics. Furthermore, essential time for coding the game logic will be required;
 - Evaluation of the game prototypes with experts;
 - Analysis of evaluation feedback and post-evaluation design decisions;
 - Implementation of the complete version of the game, with manuals and licence;
 - Documentation of the work process during the whole period of the project.

3.1.3. TRADE-OFF

After two previous steps are taken, all potential conflicts between the goals and constraints must be analysed, and either constraints or goals must be relaxed.

3.1.3.1. Target age of the final users

First of all, during the trade off, the age of the final target user group was defined. When analysing the optimal age when children with ASC will be able to fulfil all the game tasks, another 3D game, by Josman et al (2008), was taken into account. In their study, the authors were using only the road crossing task (see section 2.4), which required keyboard-based navigation skills. The target age of children users in their empirical study was 8-12 years. The results demonstrated that children with ASC didn't have specific difficulties when fulfilling the tasks. When comparing the difficulty of the tasks and the overall complexity of the environment used in Josman et al.'s (2008) experiment to the planned features of VENECA, it became clear that VENECA might require the users to be more attentive and comprehensive. Therefore, the target age was slightly increased, from 8-12 to 9-14. From this point onwards, all usability requirements during the design process were analysed referring to this target age.

3.1.3.2 Additional flexibility required

Taking into account the usability issues that experts might have, it was decided to make the environment more flexible and implement two additional features:

- **Traffic constraints:** While the realistic environment must consider many factors, it might be very difficult for some child users to take into account traffic constraints during the navigation task. Therefore, it was essential to ensure that experts who wished to focus on the navigational tasks could turn the traffic constraints off;
- **Navigation speed.** Depending on the specific motor skills of children with ASC, the experts might require slower or faster navigation speed.

3.1.3.2. Technical decisions

Taking into account all computer constraints that can affect the usability and development of the software, the optimal tool was selected: Blender. Compared to some other 3D-modelling tools, Blender has the following advantages:

-
- 1) It includes a very powerful set of tools for modelling.
 - 2) This is free software that can be downloaded from the official web site. Furthermore, it allows add-ins into initial code.
 - 3) It has an integrated Python editor that will allow implementation of the game logic without the necessity to perform highly-cost exports. This will require some knowledge of coding in Python, but compared to the time that could be spent on integration, it still remains more economical.
 - 4) Unlike 3DMax (alternative 3D-modelling software), Blender has versions for Windows, Mac and Linux platforms. This feature will allow future researchers and developers to modify the software on every of these platforms.
 - 5) The final games can be saved not only in “.blend” formats, but also as “.EXE” files which will allow the users to run this game without Blender on their computer in a full-screen mode.

As a result, of this pre-design stage, all the constraints and goals were met. Moreover, such a trade-off didn't require any radical changes in the initial goals. The decisions made at this stage made the system even more flexible. Additionally, in starting from this step it was clear what will the target age of child users be. It is very important that all these decisions were made before the design process, because it would be very costly to change some decisions (especially concerning the technical aspects) during the design process.

3.2. PRE-DESIGN STAGE. TASK ANALYSIS

After the goals of VENECA were adjusted, it was important to perform task analysis (Dix et al, 2004, pp. 511-543). Task analysis allows clear and precise specification of all the actions that the user has to take in order to achieve the final goal. There are two main types of data that are used in task analysis:

- Procedural: objects and their relations;
- Declarative: sequences of actions, and sub-goals required to achieve a goal;

Moreover, there exists another motivation for performing task analysis before the design stage. Because, as a result of task analysis, software developers achieve precise scenarios of users' actions, this data is usually used further during the generation of users' educational manuals and documentation. In the case of VENECA, such a kind

documentation will allow expert users not only to adjust the system, but also to analyse some actions that their target users will have to perform in the game mode. This understanding may be crucial for researchers in making their decisions about the inclusion of each game variable.

3.2.1 TASK ANALYSIS FOR EXPERTS' ACTIONS

There exist several techniques for the task analysis step. One of the most popular methods is hierarchical task analysis (HTA). HTA is based on decomposition. It is a very descriptive technique, which allows the designer to illustrate all the actions that the user has to perform in order to complete the goal. Furthermore, it allows illustration of all the conditions when the actions are available. This suggests a full scenario of all possible users' actions, some of which may be exclusive or alternative.

For the experts' interface, since this is not supposed to fulfil any educational purpose, HTA technology was chosen as the most clear and appropriate method. Figure 7 represents the task analysis for the experts' mode.

After specification of all experts' actions was completed, the actions in the experts' menu were analysed in terms of their relations to each other and their sequence.

- **Discretionary tasks**

The upper-level tasks, 1-5, are discretionary. This means that it is not important in which order they are performed by the research experts: the levels of believability can be specified before the type of instructions is selected. Sub-tasks 1.1 and 1.2 are also discretionary: an expert can select both of them or one of them and in an optional order.

- **Optional tasks**

The experts' mode does not suppose existence of optional tasks. All the main tasks, 1-6, are compulsory in order to fulfil the main task of adjusting the system's variables to the study. However, this does not mean that all the sub-tasks are also non-optional. An expert can select either one or both of the sub-tasks 1.1 and 1.2, and this decision is upto the researchers. There may be a case when the expert wants to use only verbally presented tasks or only tasks presented in a written form in the study.

- **Exclusive tasks**

The sub-tasks 2.1 and 2.2, 3.1; 3.2 and 3.3; 4.1, 4.2 and 4.3; 5.1, 5.2 and 5.3 are exclusive towards each other in their category. It means that if an expert selects one option, another

option for the same group will be deselected automatically. This decision has a good logical reason, because it is not possible to make the navigation speed slow and fast at the same time or turn the traffic off and turn it on for the same study. In addition to the exclusions inside each category, some of the tasks are exclusive between categories. Two of them are 5.2 and 3.1 and 5.3 and 3.1. This decision is related to the fact that the lower levels of the system's believability suppose existence of rendered images of the environment and the absence of any dynamic objects. Therefore, if an expert selects either realistic mode or a cartoon-looking 2D mode, the traffic constraints cannot be turned on, because they require the existence of dynamic objects, such as cars moving on the roads, traffic lights and a feeling of navigation through this road.

Not all these elements are possible in static 2D mode, so, the traffic constraints will automatically be deselected if 2D mode is selected. However, in order to avoid situations where the user (expert) has not noticed this change, an error message will also be displayed. Sub-tasks 5.2 and 4.1, 5.3 and 4.1, 5.2 and 4.3, and 5.3 and 4.3 are also exclusive for the same reason: as has been explained already, the 2D modes don't suppose existence of any dynamic objects; therefore, the "navigation" is simulated by means of substitution of rendered pictures. For this reason, it was decided that there may not be a higher or slower navigation speed, and it will have a default medium value.

- **Fixed sequence tasks.**

While the tasks 1,2,3,4,5 are discretionary as was mentioned earlier, all these task are sequential in their relation to the task 6. An expert cannot launch the game by means of pressing the "start" button before he has fulfilled all of 1-5 tasks, because the game does not suppose existence of any default values for game variables.

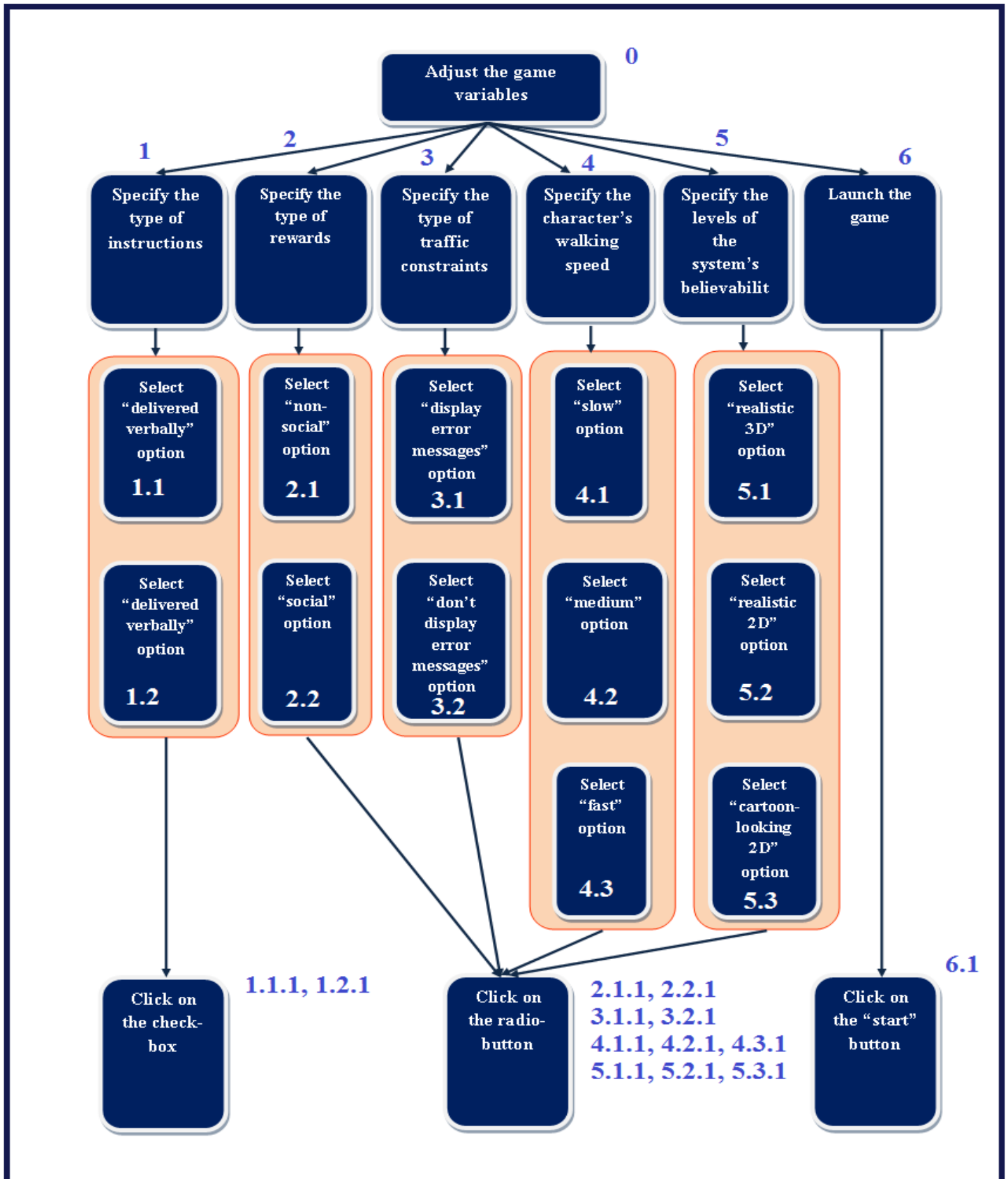


Figure 7. HTA model of VENECA for the experts' actions

3.2.2 TASK ANALYSIS FOR CHILDREN WITH ASC

HTA, which was used for analysis of the control panel, is a useful method. However, this methodology is mostly oriented on specification of particular actions. This means that while it takes into account all the functional requirements, it does not consider user requirements or specific users' skills. While the HTA method may be appropriate for the analysis of the experts' interface, it might be not be appropriate for task analysis of the game element. Since the final target user group of VENECA is very specific, there exists a high probability that the users will sometimes lack the skills required in order to fulfil particular actions. Moreover, since the game element of VENECA is supposed to be educational, a precise specification of all user skills, cognitive aspects and knowledge must be taken into account. Therefore, educational tools usually use Knowledge-Based task analysis (KBTA), which refers to the analysis of the task on the base of cognitive information. KBTA requires precise specifications of all the actions and objects that are required for a particular task. These actions and objects are connected by means of specific taxonomies. Such an approach helps to analyse what knowledge is required in order to complete particular actions, and what additional educational information may be required for the user.

After all the factors were analysed, a combination of HTA and KBTA methods was chosen for task analysis of VENECA's game element as the optimal ones. During this design stage, initial actions were analysed in terms of their hierarchy, and goals were divided into sub-goals. The hierarchy starts from the main tasks, includes all the sub-tasks, and low-level actions, such as keyboard pressing. At the final stage, for the lowest level actions, all required knowledge is analysed. This suggests an interesting approach for the analysis of all usability and functional requirements. In fact, the upper levels that describe the actions, which describe the functional requirements, suggest that are crucial in order to complete the task, while the lower levels suggest the usability requirements.

3.2.2.1 Specification of the functional requirements

Figure 8 represents the actions required in order to complete the social task with the traffic constraints, and the instructions, delivered in both verbal and written form.

Fixed sequence tasks.

Tasks 1 – 2 – 3 – 4 use a fixed sequence. This means that a task cannot be performed before the previous one is accomplished. The sequence of locations that the user has to reach is very strict and the user is not able to change it, or skip a location in order to reach another. Within task 1, sub-tasks 1.1 – 1.2 – 1.3 – 1.4 also use a fixed sequence. Tasks 1.1.3 – 1.1.5 are also sequential in most cases. However, there exist cases when this sequence is not supported, for example, the tasks that require further navigation after road crossing.

- **Time sharing tasks.**

The pairs of tasks 1.1.1 and 1.1.2, 1.2.1 and 1.2.2, 1.3.1 and 1.3.2, and 1.4.1 and 1.4.2 use the time sharing principle. This means that they can be done at the same time: the user reads the task and hears the verbal representation at the same time.

- **Discretionary tasks.**

The tasks that are related to navigation are discretionary. This means that the main purpose is to reach a location, but the order in which the user navigates does not matter: he can fulfil the same task in all possible ways, and he is absolutely not constrained by a particular navigation path.

- **Cyclic tasks.**

There is another way of thinking about navigation tasks: the user has to navigate until he reaches a location. This can sometimes lead to cyclic performance of the same actions: going forward, backward, etc.

- **Waiting tasks.**

The road crossing task is based on the waiting logic: the user has to wait for a particular event in the environment (the light on the opposite side becomes green) in order to cross the road.

- **Optional tasks.**

Finally, specific directions in the navigation tasks may be optional. This means that the user is not required to fulfil all the navigation actions in order to accomplish the task. For example, in order to reach the city bank, he can only turn left and go forward.

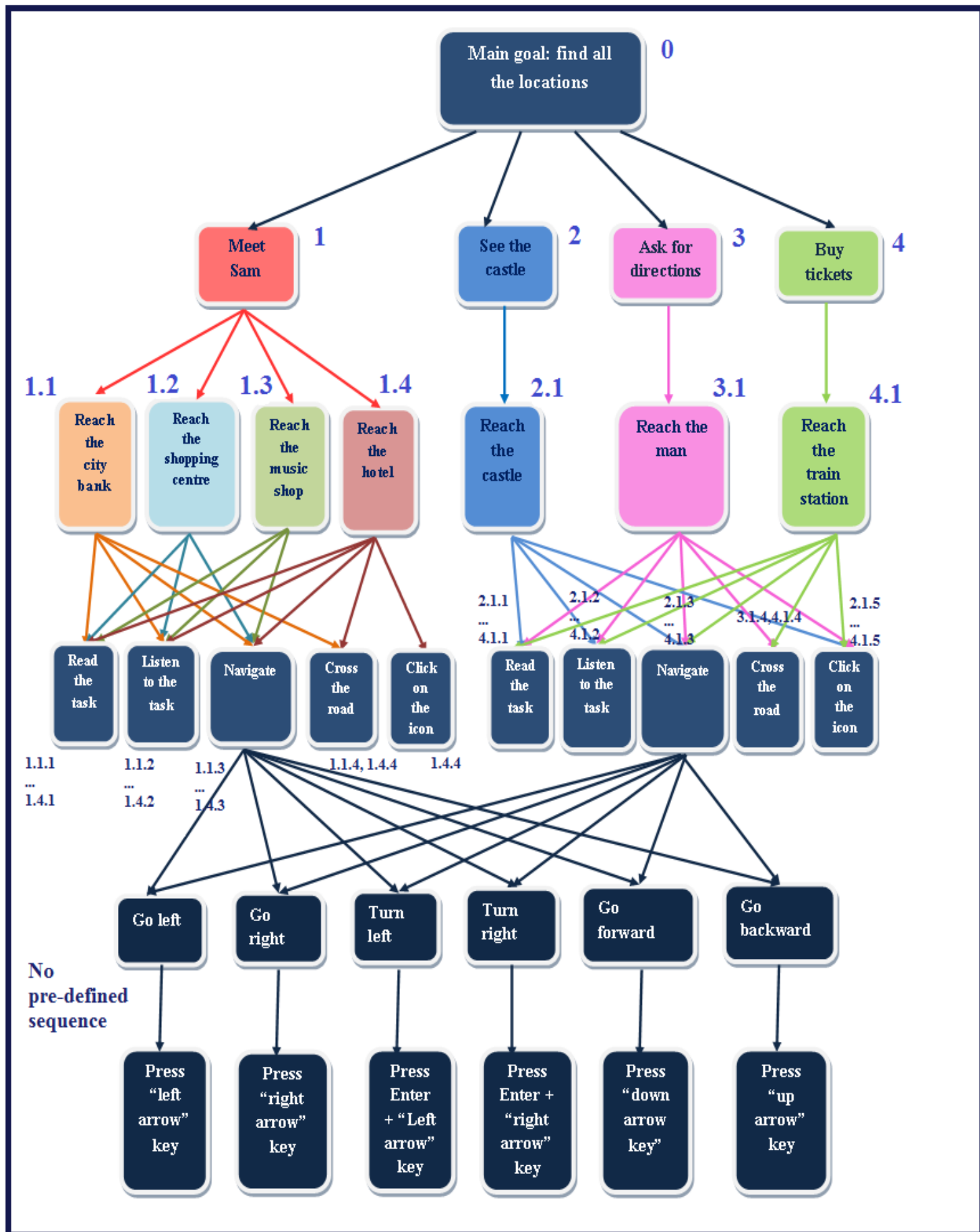


Figure 8. HTA task analysis for the most complex game mode

3.2.2.2 ANALYSIS OF FUNCTIONAL REQUIREMENTS AND SPECIFICATION OF USER REQUIREMENTS

The KBTA approach suggests a very clear illustration of all the tasks in terms of their functional requirements, and a very convenient way for analysing the usability requirements. By looking at the end-actions, it is possible to define all specific skills that users are required to have in order to accomplish the high-level tasks. All these skills were analysed in details before the design process was launched, in order to ensure that they would not create problems for children with ASC.

3.2.2.2.1. Ability to read the task

In case, the task is presented in a written form, child users must have fluent reading skills. Therefore, it is important to analyse whether children of the target age have enough skills in order to read the written text, and what are the user requirements are for this task.

There are many research studies that concentrate on language comprehension of children with ASC (see Chapter 2). Delayed language is one of the main symptoms that leads to the early diagnostic of children with ASC, according to Dahlgren & Gillberg (1989). However, it is important for the design to concentrate only on the language aspects that can affect reading. According to the research by Vacca (2007), there exist several factors that can affect children's reading abilities, such as inability to concentrate on the context, which is related to lack of attention, and absence of motivation. According to Evans (2007), high-functioning children with ASC can become very good readers, but there exist several challenges during the teaching process. In addition to motivation and attention difficulties, Evans (2007) mentions the challenge of recognizing different grammatical rules. Another study, by Diehl et al. (2006), shows that the grammatical development of children with ASC, as well as their morphologic and phonologic comprehension is delayed compared to the typically-developing children (TDC). However, there is no tendency for children with ASC to have impairments in these language skills.

An interesting piece of research carried out by Diehl, Bennetto & Young (2006) suggests a novel criterion for evaluation of reading skill: inferential ability. In the described experiment, children with ASC having reading skills were given a story which requires analytical understanding and inferential skills: while the fact was given at the beginning of

the text, and the result was presented at the end, there was no linking information between them inside the story. The evidence showed interesting results: participants from the target group experience no problems recalling all the main the events of the story. However, they used almost no links between the facts.

It is important to establish whether there is enough evidence about whether children of the target age have sufficient skills to complete the reading task. If so, what user requirements have to be considered in VENECA? One of the most detailed analyses of reading difficulties of children with ASC, by Illand (2011), reviews many reading aspects of children with autism spectrum condition between aged 4-10 and 11-18. This range includes the target age of VENECA's potential child users. There exists evidence from previous research that many of readers of the target group and age may have very fluent reading skills. Moreover, their reading abilities sometimes outperform those of TD children. However, considering all the information given above, it becomes clear that there can be several aspects that can affect reading. These difficulties are not always easy to observe, because most of them are related to the actual comprehension of the text. Illand (2011) also mentions the problem of information comprehension, which is often overlooked by teachers and parents.

Taking this information into account, it becomes clear that children of the target age (9-14 years old) for VENECA will probably have good reading skills. However, the design must take into account some comprehension problems and assist children in their understanding of the written instructions. The usability requirements that were specified for the reading activity of VENECA are presented below:

- **No inferential information:** The research by Benetto et al (2006) mentioned earlier, provides clear evidence that children with ASC have weak inferential skills. If the design for VENECA included any inferential information that is not clearly presented, this may present the risk that, even though children with ASC will have good memorisation of all the required actions, they will still lack the actual understanding of those actions. Therefore, no inferential information must be included in the tasks. Each task must have a separate specification of all the actions, even if they are analogous to the previous actions. For example, if a child has to press the "OK" button in order to proceed in all the written tasks, this must be clearly stated for every task. If there are visual icons for every location, and the child has to press the icon in order to get a

reward, this must be re-stated for each separate task, because while the situations are analogous, the icons look different, and children may not be able to infer the required actions from the previous tasks.

- **Duration of tasks:** As mentioned by Evans (2007) and Vacca (2007), lack of attention is one of the main challenges during reading tasks. A design that only displays messages for a particular amount of time might therefore be problematic, because during that time, there might be many other factors that will grab the child's attention. The text tasks must therefore be fully manageable by children. This approach provides the option of reading the task several times, helping children to memorize information and simulating in them a feeling of control over the task.
- **Visualization:** This is a traditional approach used by many teachers in order to teach children to read. Grandin (1995) states that all children with ASC are "visual thinkers", and that the way they comprehend information is highly related to visualization. In addition, Abisgold (2007) mentions that children with ASC are very weak in reading tasks that require imaginative skills. In order to satisfy all these requirements in VENECA, it was decided to use images of all the visual objects that are mentioned in the text. For example, if the text mentions the location, there must be a picture representing this location; if the text mentions a character or an icon, all these elements must be visualized. This approach will increase the users' comprehension of the tasks, and, moreover, it will avoid situations where they might be required to use imagination.
- **Context cues:** This term was used by Vacca (2007) as one of the main teaching techniques that help to motivate reading. Gray (1995) developed a specific technique that uses social stories in order to help children with ASC to read. Such stories are able to provide an interesting reading context and motivate users. Returning to VENECA, all tasks are presented in the context of a story, and are related to the main story, in both social and non-social modes. The evidence that social stories are able to improve children's reading skills provides a new interesting perspective: while written tasks are used to present the information related to the main story, the main story itself can be used by the researchers as an additional cue that might increase children's reading capabilities in an indirect way.

3.2.2.2.2. Ability to comprehend the verbally-presented task

In the previous section, some difficulties in the comprehension of written text were analysed. However, children with ASC are usually known to have much weaker auditory skills. Loveland et.al (1989) mentioned that one of the main reasons for weak comprehension of verbal information in children with ASC is the lack of emotional support. Individuals, initially having problems with social understanding, usually experience great challenges in recognizing people's feelings when verbal information is not supported by visual elements (see section 2.2). If a person is very angry or upset about something, but expresses his thoughts in a very controlled way, without emotions or voice intonation, the target group of users would not be able to comprehend the meaning of his words.

Taking into account the fact that verbally presented tasks will be the most difficult for users to understand, the initial research question that VENECA allows experts to examine (see Chapter 1) was not based on a strict comparison between verbal and non-verbal tasks, but rather on whether the verbally presented task is able to affect the comprehension of written information in any way (either positive or negative). However, even considering that the verbally presented task will always be accompanied with written text, it must be as adjusted for the target group as possible. The usability requirements for the verbally presented tasks are specified below:

- **Speed:** Children with ASC usually have relatively slow processing capacity for any kind of information. However, qualitative information is not enough to make an appropriate decision. When talking about an ASD group of users, any design decisions must be very objective. It is not enough just to make the speaking speed slower than one would expect; it is important to adjust the speed as precisely as possible based on previous empirical studies. In order to adjust the pronunciation to a particular speed, it is important to know the precise delay in verbal comprehension. One of the recent research studies, carried out in the Children's Hospital of Philadelphia and published by Roberts et al (2010), presents very valuable facts about children's verbal processing speed. The mean age of ASD participants in the author's experiment was 10, which tallies with the target age of VENECA. The experiment by Roberts et.al (2010) was based on auditory stimuli of different frequencies (50 msec. and 100 msec. long), which were presented by means of specific auditory software via specific experimental

earphones. As a criterion for evaluation of verbal stimuli processing, the authors recorded the eye blinks and heartbeat speed of the participants. Figure 9 presents the results from this study for the latency in the right hemisphere. It shows that across all frequencies ASD participants demonstrate 10 msec. delay compared to TD children the same-age.

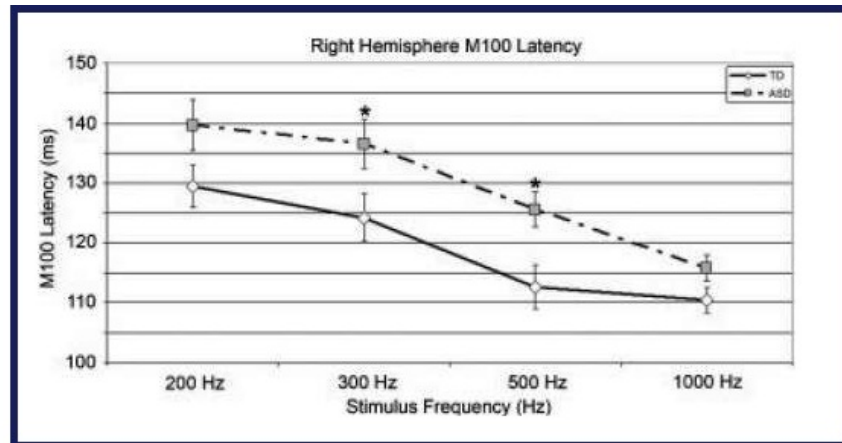


Figure 9. Statistical analysis of auditory processing latency in Roberts et al.’s study (2010)

These summary results suggest that children with ASC demonstrate auditory comprehension which is 0.01 sec slower than in TD children. This result gives a valuable qualitative data for determining VENECA’s speaking speed. In order to generate verbal instructions, VENECA uses the TTS system, which allows flexible selection of speech speed (Figure 10). However, adjusting the speed to 10 msec. slower than the norm could be problematic. The first problem with selecting the speed can be related to the lack of precise grading. As shown in Figure 10, the original system didn’t suggest any grading in milliseconds. Furthermore, if foreign timers are used, there may be a risk that the timer and the moment when the “play” button is pressed are not synchronized, especially when talking about milliseconds that may not be noticed.

In order to avoid all these specified difficulties, an additional, automated, measuring system was developed. In order to make the testing very precise, the timer was developed using Blender, the same program that was used for the implementation of VENECA. The accuracy of counting was set to 0.001 sec (this is the default setting for the “Timer” property in Blender, which perfectly suits the testing). The property was assigned to the “Text” element, in order to visualize the time. After that, several audio files that produce the same word spoken with the same pitch and voice and recorded by the same TTS system

were integrated into the software, and the speaking time was then recorded. This approach ensures that audio files started running at the same time as Timer. As a result, the final spoken speed of VENECA was exactly 10 msec. slower than the normal spoken speed.

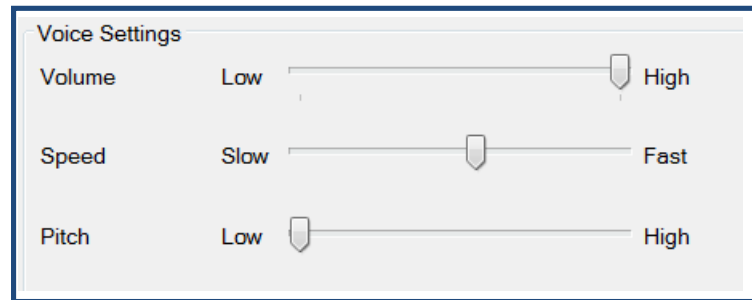


Figure 10. Voice settings of the TTS system used in VENECA's design

- **Pitch:** Pitch of sounds is another factor that may affect comprehension of speech by children with ASC. A study by Russo et al. (2008) tried to investigate the influence of pitch on children's comprehension of syllables. All the syllables used in the authors' experiments were taken from the everyday words and pronounced by a native English speaker. The results were statistically analysed on the base of errors' frequency. Figure 11 represents these results. This shows that at the same level of pitch strength (0.25), the frequency of errors is 10 in children with ASD is 10, and 8 for TD children.

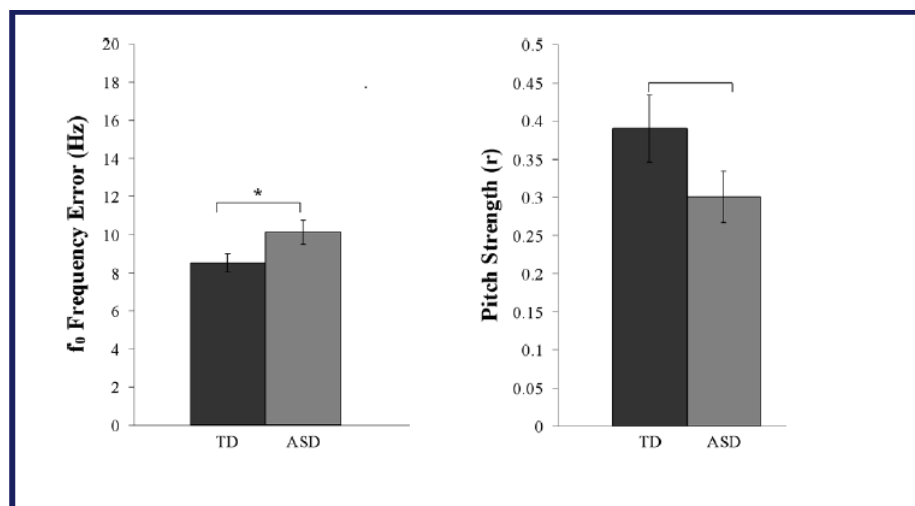


Figure 11. Comparison of the errors' frequency for different pitch levels from Russo et al.'s study (2008)

Given that children with ASC demonstrate an almost linear increase of errors with increased pitch, the level of pitch was set to the minimum value for all the verbal tasks. In addition to this adjustment, pre-recorded audio files were further modified inside Blender

during the process of loading into the game in order to achieve the least possible pitch and increase users' comprehension.

- **Intonation:** As mentioned at the beginning of the analysis of verbal comprehension in children with ASD, one of the main reasons for their weak comprehension of auditory information relates to their inability to understand emotions. As mentioned by Loveland et.al (1989), all the phrases must be supported by specific intonations, otherwise children will experience high difficulties in comprehension.

VENECA uses the TTS system for the generation of verbal tasks. This may not be most optimal decision, because synthesized speech is usually known to sound very emotionless. However, for a design process that supposes many iterations and changes, it is the most flexible way of generating speech. In order to make it more suitable for the target group, the optimal voice from existing English-speaking male voices with a British accent was selected. However, the first tests of the TTS system still demonstrated some limitations and lack of required intonations. For example, one of the tasks includes a sentence that predicts user about traffic rules: *“Be careful on the roads: the traffic rules are very strict in Adventureland!”*. Obviously, this sentence has to be pronounced with specific intonation, demonstrating a caution. In such cases, the stressed words were specified by means of using SSML tags, a standard language used on the low level of the TTS system. This approach required sufficient time for the analysis of the SSML syntax, but, as a result, the speech became more fluent, expressed particular emotions and made appropriate pauses. Moreover, it allowed developer to “teach” the system some non-English words, such as “Adventureland” (the name of the virtual city) which it previously tended to read letter-by-letter.

3.2.2.2.3. Ability to use a keyboard and mouse

As shown in HTA diagram (Figure 8), the next action is “navigating”. However, the navigating itself is not the lowest-level action. As showed in Figure 7, it is directly based on the ability of the user to press different keys on the keyboard. This lowest-level action must be analysed in terms of the target users' skills. The sub-subsequent task, click on the icon, is also related to children's computer skills. Therefore, these skills will be analysed in one section.

There are many computational games that exist in the area of ASC even for much younger children and which demonstrate their ability to use a keyboard. The one that is closest to VENECA's action is the study by Josman et al (2008), which has already been mentioned several times. The target user group of Josman et al.'s (2008) experiment comprised children with ASD between 8 and 12 years old, which does not exceed the age of potential final users of VENECA. The study provides clear evidence that children in the target group are able to use a keyboard in order to succeed in analogous tasks. However, there exist several simplifications that can be made in order to assist them in their task. These simplifications refer to the hardware rather than software requirements, but it is important to include these ideas in the form of recommendations or suggestions to future researchers. Research by Chen and Bernard-Opitz (1993) investigated the difference between personal and computer-assisted instructions. The authors mention that, in the studies, two out of four children demonstrated difficulty in finding particular keys on the keyboard. There are several ways to avoid this problem. For example, in their experiment, Josman et.al (2008) used colourful stickers that were attached to the keyboard keys in order to simplify the process. An alternative solution may be found in the modern technology. Nowadays, there are many versions of peripheral devices that are produced for children in the target group in order to simplify tasks. For example, there exist keyboards with a reduced number of keys, in order to reduce confusion, some keyboards use specific colours in order to visualize the groups of keys according to specific functions, another group of keyboards use specific graphical icons on the keys, in order to simplify understanding and make visual comprehension more explicit. With regard to the mouse, there are many computational games, which are developed for younger user group of the smaller age, and provide empirical evidence that children can successfully use a computer mouse in order to accomplish a task. At the same time, there are many specific mouse devices existing in the area of ASC, with only one key, which suggest more simplified design. In order to improve the users' capacity, these suggestions and recommendations for the hardware must be included into documentation.

3.2.2.2.4 Ability to cross the road

The task of crossing the road requires the combination of all the skills specified above: ability to navigate and press the keyboard keys as a lower action. Moreover, if the traffic constraints are turned off, children will need to comprehend the verbally and visually-

delivered warnings, which uses their reading and auditory skills, as described above. After the warning messages have been understood, users will be required to close the message by means of clicking on it with the computer mouse. Because all these actions were justified above, the task of crossing the road does not require additional analysis.

3.3 FROM PRE-DESIGN TO DESIGN

The pre-design stage has helped in the analysis of many goals and also in making some preliminary design decisions. The task analysis stage is a very helpful methodology for understanding the logic of the software and providing some usability requirements. However, it is not possible to consider all the requirements just during the theoretical analysis of the system. While the KBTA analysis of the children's mode described in the previous section has specified some of the design decisions that were made during the pre-design stage, all of these decisions are directly related to the users' actions: reading, listening, clicking or pressing the keys. However, the complicated virtual environments may include a large variety of elements and events that have a crucial effect on the users' comprehension and behaviour even if they are not related to the users' actions directly. These will be described in the next chapter called "Design and Evaluation".

CHAPTER 4

DESIGN AND EVALUATION

4.1 OVERVIEW OF THE CHAPTER'S STRUCTURE

Returning to the waterfall model (Figure 6), the next three steps: design, prototype testings and analysis of evaluation results, form a cyclic process. This is one of the classical approaches of software development, which supposes several design iterations, followed by prototype testings before the final version is implemented. VENECA was designed on the basis of the same iterative principle. There were three prototype testing stages between different design iterations of VENECA. In order to describe this process, this chapter is divided into four main sections, each one covering a separate design iteration and analysis of its evaluation feedback. Each design iteration section will be followed by an “Evaluation” sub-section. This style of describing the implementation process, which does not separate “design” and “evaluation” steps into two chapters, will allow for the avoidance of the case when a reader has to switch between two chapters in order to understand the reasons for particular design changes. Moreover, this approach of delivering information will provide a better comprehension of both stages in the same order that they were following during the original iterative design process.

Since the first prototype of VENECA didn't include the control panel for experts, the first subsection will not contain any design decisions concerning the experts' interface. However, starting from the second prototype, all design decisions will be divided into two sub-sections: decisions that refer to the experts' interface and decisions concerning the game element of VENECA.

The sections, describing design decisions, also have specific organization. Taking into account the fact that the first iteration considers a large scope of design decision, all decisions are classified into three main groups:

- Believability requirements
- HCI principles
- Technical requirements.

During description of the subsequent design iterations (2-4), the sections first present particular changes and then analyse their importance based on the same believability, HCI or technical requirements.

Moreover, it is worth highlighting that this chapter does not contain any specific subsection called “user requirements” that separately discusses the decisions made for the target user group. The reason for choosing such a structure lies in the fact that during the design process, each design decision from these three classes of requirements was analysed in terms of its suitability for the final target user group. Any alternative approach of making the design decisions, separately from the final users’ requirements, could be extremely risky, because it would not consider possible contradictions between two groups of requirements. Therefore, in the context of each requirement, there are three main points to analyze:

- Its importance for a particular class of requirements
- Its importance for children with ASC
- How the requirement was implemented (or not implemented) in VENECA, considering the trade-off between these two previous aspects.

4.2 DESIGN OF THE FIRST PROTOTYPE

This section discusses the design decisions that were made during the first design iteration. At the end of this stage, only the first, most complicated, mode of the game, which included social rewards and a highly believable 3D environment (Figure 12) was developed.



Figure12. Overview of Adventureland, virtual 3D city, designed for the first prototype

4.2.1 DESIGN DECISIONS CONCERNING BELIEVABILITY

Throughout this thesis the term “*believability*” is used as one of the main criteria for VENECA. As stated in Chapter 1, one of the main goals of this project was to implement a

tool that could help experts find the optimal balance between the ecological validity and comprehension of VEs. Therefore, during the design of VENECA, it was important to implement a high degree of the system's believability, which would consider and eliminate some shortcomings of the analogous systems, currently existing in the area. In order to achieve this goal, it is important to analyze what criteria define believability. What makes the system look "believable"? As highlighted by many authors (see Bhatt (2004), Tence (2010)), "*believability*" is a highly subjective term, because different software developers and users may have various understandings of a "*believable environment*". Moreover, even in highly believable and technically complicated video games there exist some aspects that make them different from the real-world. In addition to this fact, some assumptions and simplifications are usually made on purpose in order to adjust the system to the target user group, and make the game more controlled and educative. A highly believable educational game must have a good balance between simplicity and believability. Moreover, different authors suggest their own hypotheses on factors that can affect believability of the VE. Therefore, this section presents design decisions that are suggested by the believability criteria found across different authors.

4.2.1.2 BELIEVABILITY QUALIFIERS

4.2.1.1.1. Consistency

Significance of the requirement for believability: According to Bhatt (2004), consistency is one of the main qualities of a believable system. A consistent system must provide users with identical responses in all analogous situations. If the system reacts in a particular way to an action and does not react the same way to an analogous action, the users can lose the feeling of control over this environment and can no longer predict the effect of their actions. This usually leads to the overall negative attitude towards the system.

Significance of the requirement for children with ASC: When talking about the final target user group, the importance of this requirement becomes crucial. The main symptom that can potentially be related to this requirement is their "stereotypical thinking", discussed in Section 2.1.3 when talking about repetition. Children with ASC are usually known to have a very stereotypical comprehension of their environment, and their repetitive patterns make them behave exactly the same way in analogous situations. Moreover, in Section 2.1.3 it was mentioned that they are usually biased towards

monotonous tasks, and any unpredictable changes might be highly stressful for them. Given all the information, it can be concluded that, while consistency is an important aspect for all believable games, children with ASC will rely especially highly on this aspect when playing the game.

Implementation of the requirement in VENECA: It is important to ensure that the system guarantees consistency for all of the actions of the children users.

- **Navigation:** For the navigation activity, it was decided to use the default keyboard keys. As a result, the location was fully controlled by the user in a dynamic way. When the game is launched in the 2D mode, the navigation task does not create any problems. However, when a 3D navigation is used, the user is supposed to rotate flexibly in the virtual space. Therefore, it is important to ensure that the program is able to detect the location intelligently, and is not dependent on any coordinates in the space. Otherwise, what is “forward” for one angle could be “backward” for another one, and the users would not receive consistent responses to their navigation activities. As a result, the first prototype of the game included absolutely an consistent and artificially intelligent navigation mechanism.
- **Road crossing:** This activity refers to another task, which required even more effort to ensure consistency. Two main aspects must be considered here: the current time and location of the user in the 3D city. There was a risk that constraints could work well for only a particular location. Gustafsson et al (2006), in their game, which was also based on a storytelling approach during a navigational task for TD children, mentioned this problem as one of the critical challenges of all VEs that suppose absolute dynamic navigation. The authors also implemented road crossing scenarios, and mentioned that it is never possible to predict the path of the character or guess from which angle and at what time the user will reach the target location. The same challenge had to be resolved during VENECA’s design. In addition, the constraints have to work only at a particular moment in time: when the traffic light was illuminated “red”. Moreover, both of these factors had to be considered in a relation to each other: the system has to check if the character is moving at a particular location at a particular moment of time and display error messages only at that moment. At the end of the first prototype design, the constraints were working consistently for all the locations where the road crossing signs appear and were precisely synchronized with the traffic lights.

- **Messages:** For all the messages that appear on the screen, there is only one action that allows the user to close the message and proceed to the next step: clicking the “OK” button (Figure 13). The system would not be consistent if it used different ways of closing analogous messages.
- **Clicking on the appearing objects:** In the social mode, the user was required to click on the object which appears on the screen in order to get a reward. It would not be a consistent design, if such objects were to appear only for a particular location. The user would expect the same icon to appear for other locations too. As a result, for all the target locations, there were implemented corresponding visual objects that were logically related to the target, and the user was required to click on those objects.

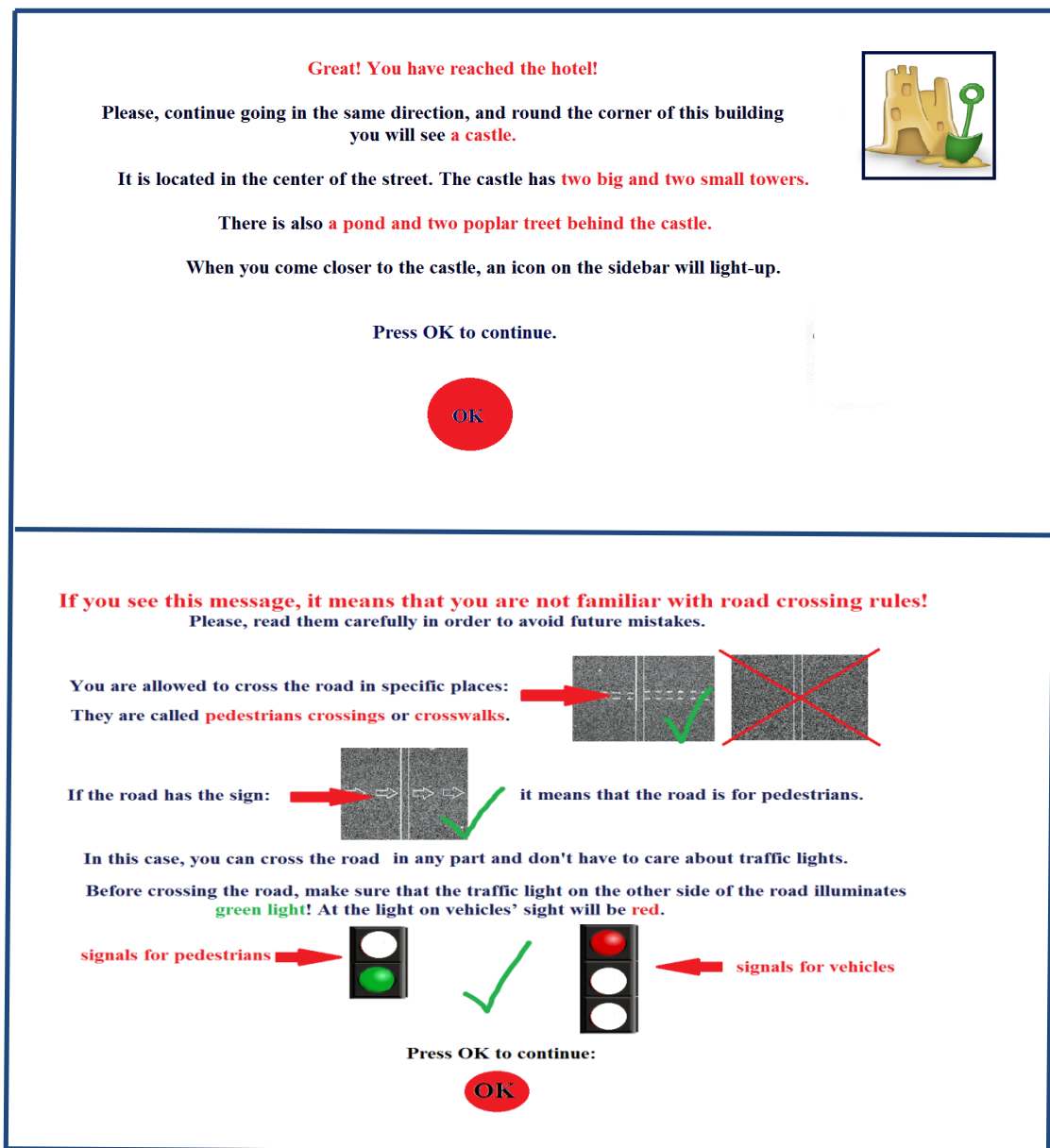


Figure 13. Examples of messages that use “OK” button in order to proceed

4.2.1.1.2. Agency

Significance of the requirement for believability: Agency is the second qualifier, mentioned by Bhatt (2004). The system must support agency in order to be believable, because it ensures that all the actions of the user have results analogous to those during the real-world tasks. In his description of agency, Bhatt (2004) mentions sounds that are usually heard by the users during their real-world activities, and emotions of the game characters that are usually observed in analogous real-world situations. In cases where the game does not satisfy the principles of agency, it cannot be considered believable enough.

Significance of the requirement for children with ASC: As for the previous requirement, stereotypical judgement and thinking are main symptoms that might be related to the requirement of agency. However, when discussing agency, there exist differences in the perspectives from which it could be analysed. For consistency, stereotypical thinking was a result of users' expectations according to their observations during the game playing process. Meanwhile, for agency, stereotypical thinking refers to the experience that children can potentially transfer into the game from the real-world. For example, if for an action such as screaming, they were usually observing someone's anxiety, they would expect the game characters to become anxious as well. There is another aspect that can suggest an opposite way of thinking about agency. Educational games, especially those with the purpose of being highly believable, must correspond with real-world situations in order to increase the generalization factor. If the system generates logically wrong reactions to the user's actions, the probability that children with ASC will transfer these "wrong" observations into the real-world tasks becomes much higher than for TD users, who are able to discriminate game assumptions and simplifications. Instead of being educative, a non-agent system might have a negative and confusing effect on a child's real-world behaviour.

Implementation of the requirement in VENECA: During the design process, there were several game elements that required a strong agency.

- **Traffic constraints.** When navigating in the real-world environment, children may need to cross the road. Software that does not consider any traffic constraints in the design would be very risky to use in the research studies with the target user group, because it might generate a pattern of navigating by means of ignoring traffic rules.

This is a good example of how dangerous an effect non-justified software might have for children with ASC. In order to avoid this problem, VENECA includes the traffic system. The traffic light colours correspond to the real-world ones. Moreover, there are two sides of the traffic lights: for pedestrians and for vehicles (Figure 14). The lights are change in correspondence with the real-world traffic-lights and are synchronised with each other so that when the lights on the vehicles' side are green or yellow, the pedestrians observe the red light, and when the light on the vehicles' side changes to red, the pedestrians see the green light. The movements of the cars were also implemented in an agent way: they always stop near the road-crossing signs when the lights on vehicles' side are red (Figure 15). All these features are important to ensure that the user will observe traffic behaviour analogous to the real-world.



Figure 14. Street view of Adventureland. Synchronized traffic lights on the vehicles' and pedestrians' side

- **Objects appearing in order to get the social reward:** When the user completes a particular task, there is an object which appears on the screen in order to present a reward. Inclusion of such objects was suggested by HCI principles, which will be introduced later. The presentation of these objects is entirely related to the actual objects that children would expect to see. For example, when the user comes closer to a building and wants to call on his friend, a visual object representing the “door bell” appears, and the user has to click on it. For the castle, the visual object is represented

in the form of an ancient “door ring”; it would not be an agent design decision if the same modern “door bell” were presented for the castle.



Figure 15. Cars stop near the road crossing locations when the traffic light on vehicles’ side is red

- **Social scenarios.** When giving a description of agency, Bhatt (2004, p 2) mentions that it allows designers “*to ensure that all the actions of the player had meaning and purpose*”. This approach is one of the aspects not implemented in several analogous games, such as games used by Rutten et al (2003), and Josman et al (2008), described in Chapter 2. It is important for the user to have a feeling that the game tasks have a particular meaningful purpose. Therefore, VENECA includes a game story that takes place in Adventureland, a virtual city. Such an approach can motivate users to navigate in the context of this story. As a result, before the users start the task, they already have particular expectations of what they will get as a result. When the character navigates to the hotel in order to meet with the friend, and clicks the door bell, the player would expect the actual friend to appear and greet him. In case the characters are going to see the castle, the player would expect someone to show them the castle, or at least tell them something about this castle. When the characters are asking for directions, they would expect other characters to appear on the screen and

show them the directions. Such scenarios help to ensure that the user understands the meaning of their actions.

4.2.1.2. FUNCTIONAL REQUIREMENTS FOR BELIEVABILITY

4.2.1.2.1. EVENTS

Significance of the requirement for believability: Events are essential elements of VEs that allow implementation of game logic and are related to the techniques used for transitions between the states of the game (Bal, 1999). According to Bhatt (2004), events are presented as a sequence of three main actions:

- Possibility
- Event
- Result.

In case, during the transition, any of the elements in this structure are ignored, the game cannot be considered believable, because the result cannot appear without any potential possibility or without any preceding action of the character. For example, if the scene includes one slowly moving car, and the car suddenly turns over without any particular reason given from the surrounding environment, this would be an example of a result observed without any preceding event and possibility.

Significance of the requirement for children with ASC: One of the main problems of children with ASC which requires a strong structure of events, is their difficulty in inferring information, which was mentioned in Chapter 3. Even during real-world communication, when all the events have logical structures, children may experience confusion. For example, if the game character starts crying without any particular reason or prior event, children with ASC may become highly disappointed by the fact that they cannot understand the reason for this event.

Implementation of the requirement in VENECA

In order to make the events in the game well-structured, all of them are controlled by the user. The probability of every possible event is explicitly stated for every task. Considering the inferential difficulties of children with ASC, every action is described by means of specifying its probability: “...when you come closer to a location, the question sign will appear...”; clear presentation of the expected event: “click on this sign”; and specifying the

result of the action in the context of event: “...click on the question sign *to ask for directions*”.

4.2.1.2.2. LOCATIONS

Significance of the requirement for believability: Location forms a crucial part of VEs, because it determines the scene where the game takes place. Moreover, design decisions regarding location usually define the position of characters in the space. At the first stage of game development, it is highly important to determine the purpose and context of the game. If the VE is supposed to be a fairy-tale, the objects must have the corresponding features, and for the “cartoon” scenes, they must look more colourful and attractive. VENECA represents a part of the city, and therefore it must look very close to real-world streets. There are many aspects that might be considered within the scene itself, such as the quality of the textures and, the physical properties of the objects or their sizes.

Significance of the requirement for children with ASC: One of the main motivations for the implementation of a highly believable environment was the fact that children with ASC are very weak at generalizing their skills. A study by Plaisted (2011) that analyzes different aspects that lead to the reduced generalization in children with ASD, highlights how significant minor changes in children’s everyday environments can be. Unlike TD children, they usually feel difficulties in transferring their knowledge into environments that differ from educational environments or classrooms. Therefore, teachers and parents are usually trying to make either the classrooms look more similar to homes or homes look more similar to the classrooms in order to assist children in their educational process. Bergeson et al (2008), define different factors that must be considered by both teachers and parents during the educational process. When describing important features of educational environments, such as classrooms, the authors mention that due to a specific comprehension of space, children with ASC must have a feeling of boundaries between areas, and therefore, each area that refers to a particular activity must be clearly specified by means of visual signs. In addition, it is important to reduce distractions, such as bright light and noise. This evidence means that the researchers may have a risk that even small inconsistencies with the real world can lead false sense of progress.

Implementation of the requirement in the game design

- **Colours**

Colours play an important role in games, designed for children. A colourful scene tends to motivate and engage them more, while inappropriately adjusted colours tend to decrease their motivation. According to suggestions for analogous virtual games for children with ASC, such as the one used in Rutten et al.'s study (2003), it is better to use blurred colours in order to help children concentrate on the task. Therefore, for the highest level of realism, it was decided to use textures closer to real-world ones. These were taken from the free collections of an architectural website, from real-world photos of the buildings. These form one of the main factors that help to make the system more realistic (see Figure 16).

- **Physical features of objects**

The term “physical features” covers different characteristics of objects, such as textures, sizes, gravity and states. Gustaffson et al (2006), in their game that is also based on storytelling inside a navigational task (for TD children), mentioned the importance of all geographical objects to fulfil their everyday meanings. An environment with a “traffic light” object higher than a “building” object would contradict the physical features of real-world objects. Therefore, it is important to scale the objects coherently. When objects are supposed to be made of rigid textures (buildings, cars) the user will probably expect to observe the same physics in the game. One of the initial challenges of the model was the fact that all the “textures” are represented by means of images, and while the image represents a rigid material, they could easily be passed through by the user during navigation. Therefore, it was required to implement navigational constraints along all the axes for such objects. The states of objects also refer to their physical features, and believable VEs must consider these. For example, a scene uses one object which is a pond with water: since the water has a liquid state, it is not enough to put a static image, a really believable environment would also implement the “liquid physics” of water, making it more dynamic.



Figure 16. Intensiveness of colours used in VENECA

- **Shadows.**

Shadows and lights are additional features that affect comprehension of a scene. Highly advanced virtual environments with the purpose of making the scene believable implement shadows for all the objects. In addition to making the scene believable, shadows have an indirect effect on navigation: when the user comes closer to a particular object, the shadow can serve as a visual indicator, which changes according to a particular location in the space (Figure 17). For some of the textures that use colours that are very close to “white” it was observed that additional lighting makes the details invisible, and the comprehension of the building itself less believable. Therefore, for some limited amounts of textures, it was necessary to turn the lighting and shadows off.

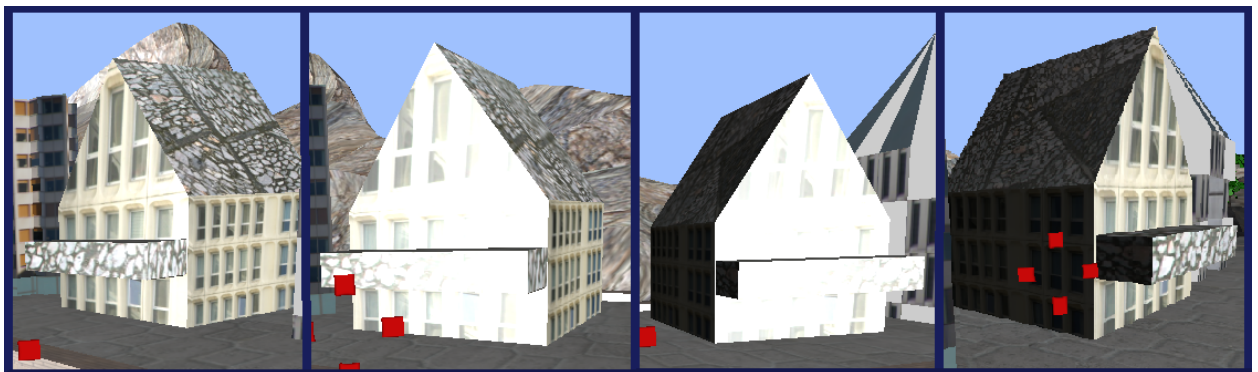


Figure 17. Shadows for the same building that change for different locations in space

- **Field of vision**

The visual field does not form part of the scene, but its adjustment is directly related to the part of the scene that will be presented to the user. The design of visual field (also referred to as field of vision or FOV) requires a very detailed analysis. Unlike 2D games, which use rendered pictures, the background scenes of 3D VEs dynamically change, and it is important to ensure that the field of vision always provides enough information to make decisions during navigation tasks. FOV also has a direct effect on the distance relations between visual objects. In order to make the game believable, the FOV was adjusted to an optimal height in order to simulate the usual level of peoples' eyes during navigation (approximately 1.5 – 1.6 metres, proportioned to the environment's sizes). Moreover, in a design of VEs, it is problematic to select an appropriate amount of visual information for the FOV, because while a large amount of visual information is likely to confuse the user, a FOV with objects that are too detailed, which does not provide an overview of the surroundings, will disorient the user and make comprehension harder. TD people have an almost 180 degree FOV, which is horizontally parallel to the angle of eyes. However, only 120 out of 180 degrees form so-called "binocular vision", and the remaining 60 degrees are comprehended by humans as peripheral information. These features were simulated in VENECA's FOV by means of adjusting the depth of the camera.

- **Focus of FOV or "cyborg's dilemma"**

The term "*cyborg's dilemma*" was used by Biocca (1997) in his analysis of the different mental effects that different avatars (in official literature also referred to as "*embodiments*") have on users' comprehension of VEs. The analysis suggests different challenges, such as social and visual differences, from which can raise different questions in users, such as "*Is this body really me?*". In stereotypically thinking children with ASD such design can arise even more questions. Moreover, because people do not see themselves from the point of view of another person during real-world navigation, inclusion of an avatar during the navigation task would not be agent. Therefore, other possible solutions for the problem were analysed. One of them is the inclusion of some parts of the body that are usually seen by the person during the walking process: hands or feet, for example, as used in an experiment by Phillips et al (2010). This approach could increase the players' feeling of space; moreover, it would not contradict believability principles. However, in order to see the foot, the camera must be located strictly parallel to the ground. Even in real-world tasks, people have to look down, in order to see their feet.

The idea of rotating the FOV periodically up and down could be very disorienting during navigation. Therefore, at least before the first prototype testing, it was decided to include a cursor which would simulate the point of presence in the space (Figure 18).



Figure 18. Red cursor used in the first prototype in order to indicate presence in space

4.2.1.2.3. Timing

Significance of the requirement for believability: According to Bhatt (2004), timing is another requirement that must be considered in virtual environments. This is one of the examples when VE may require simplifications and adaptations. Before defining the time, it is important to understand that time in computer games does not always correspond with real-world time, because the game playing period is limited. For example, if the game simulates change between day and night, it is not necessary to wait 12 hours, because a user will be unlikely to spend 12 hours on this game.

Significance for children with ASC: A sense of time is a very important aspect that children with ASC usually lack. Different visual timers have been developed especially for children with ASC that help them to notice the time by displaying warnings in the verbal or visual form. In addition, for the multitasking environments it is very important for the user to be able to divide time between different tasks (recall VET environment described in Chapter 2, used by Rajendran et al (2011)).

Implementation of the requirement in the game design

As was highlighted during the literature review, for complicated environments which suggest different paths to reach locations, it is very difficult to define the optimal time; therefore, there are no time constraints in VENECA. However, one timing decision was still very important to implement: traffic timing. The traffic light can be considered as an ideal “hidden” timer which changes colours periodically, and the red colour signifies a warning. Therefore, the duration of traffic signals had to be analyzed, because, as highlighted earlier, the same game events must be shorter than in real-world tasks. In case a user had to wait too long in order to cross the road, the timing could not be considered optimal. From the other point of view, the time when the traffic-light eliminated the green light must be long enough so that the user could cross the road even with the slowest possible navigation speed. Complex testing, considering all these timing requirements, was carried out in order to adjust the traffic system to an optimal pace.

4.2.1.3. CHARACTERS

Significance of the requirement for believability: Characters form another large class of believability requirements. As mentioned in Chapter 2, the characters in VENECA had increased personality levels than characters used in other environments (Rutten et al (2003)). During their presentation of iFace – specific language that is used to develop the characters’ faces- Zammitto et al (2008) mention several factors that make the characters believable. Some of these were also considered during implementation of VENECA’s characters. Figure 19 demonstrates a sample character that the authors implemented by means of iFace language.

Significance of the requirement for children with ASC

As mentioned in Chapter 1 during the description of social rewards, one of the potential reasons for insufficient social motivation in children with ASC can be the existence of unbelievable, static and unattractive game characters (Kohls et al (2012)). The social mode of VENECA supposes the existence of characters, and therefore it is important to make them attractive for players. Moreover, taking into account the social difficulties that children with ASC experience: their inability to understand social situations, follow joint attention, and interpret emotions of other people even in the highly believable real-world situations, the implementation of the virtual characters becomes one of the most important parts of the game design that supposes any kind of social scenario.



Figure 19. Character implemented by means of iFace language (Zammitto et al, 2008)

Implementation of the requirement in the game design

4.2.1.3.1. General appearance

A character's appearance provides important information about its personality. A character with a well-designed appearance allows users to infer its age, gender, profession, etc. The first prototype of VENECA included three characters: the Prince of Adventureland (virtual city), a boy called Sam and a stranger on the road. Unlike iFace, the modelling of characters in Blender is mostly related to artistic rather than programming skills. Implementation of the general appearance was divided into three main stages (see Figure 20).

- 1) **Implementation of the general shape.** At this stage the general shape of the future 3D character must be implemented by connecting the modelling vertexes (Figure 20, a).
- 2) **Sculpturing.** After the vertex-based model is implemented, the solid material must be applied to the shape, and specific sculpturing brushes were used in order to model the face details and make them look more realistic (Figure 20, b).
- 3) **Texture.** A character with a grey texture would not look believable, and therefore the shape of the character must be unwrapped, and textures assigned to the character's shape.

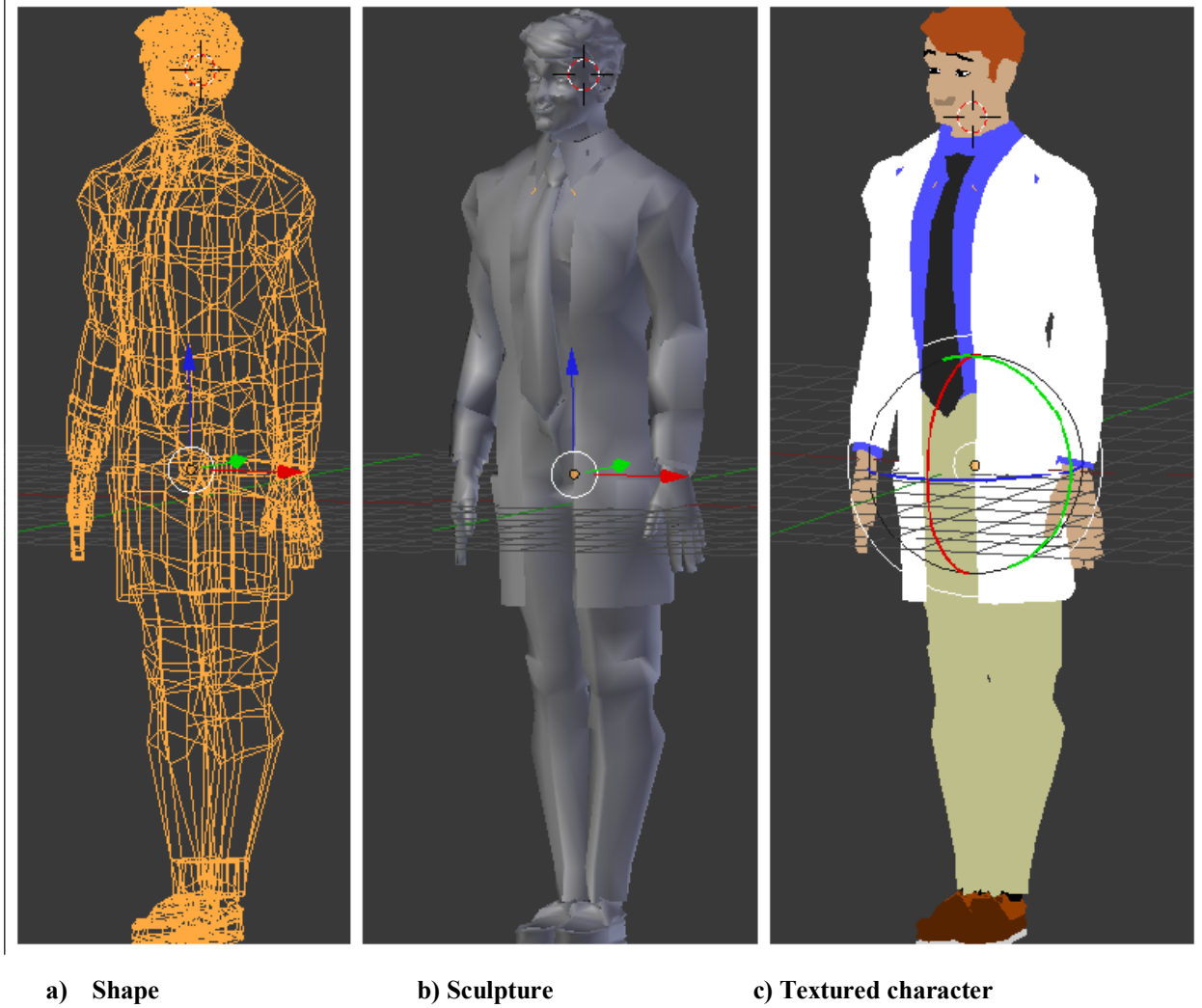


Figure 20. Three stages in the design of the character's personality

Figures 21 represents the appearance of three characters, achieved as a result of this three-staged design process. By looking at these characters, it is possible to make particular observations based on their appearance: for example, Sam (Figure 21, a) looks much younger than the two other characters.



a) Sam

b) Prince

c) Stranger on the road

Figure 21. Three game characters implemented for the first prototype

4.2.1.3.2. Speech

Speech forms another important feature of a character's personality. One of the main attributes of believable speech is voice: this must correspond to the appearance of the character. If the appearance suggests that a character is a small boy, he cannot have an adult male or female voice. Therefore, the character called Sam was assigned a child's voice. It is important to define the context of his speech that corresponds to his age, occupation and the story of the game. Moreover, a character that produces a voice without any visual support for this action would hardly be believable; therefore, it is important to implement the visual effect of mouth opening. In VENECA, this feature was implemented by means of assigning armature bones to the mouth, which would allow the speaking animation (Figure 22). The second step was to create the speaking animation, where the frequency of opening the mouth would be synchronized in time with all the pauses and speaking moments in the speech. This process can never ideally resemble the human's speech, but the speech of a believable character must be synchronized with the sound. Head movements are another aspect that can make the speech even more believable. This action allows for highlighting some parts of the speech, expressing agreement or disagreement with the context. Sometimes, head movements can also partially express the character's emotions, such as sadness (the character inclines the head).

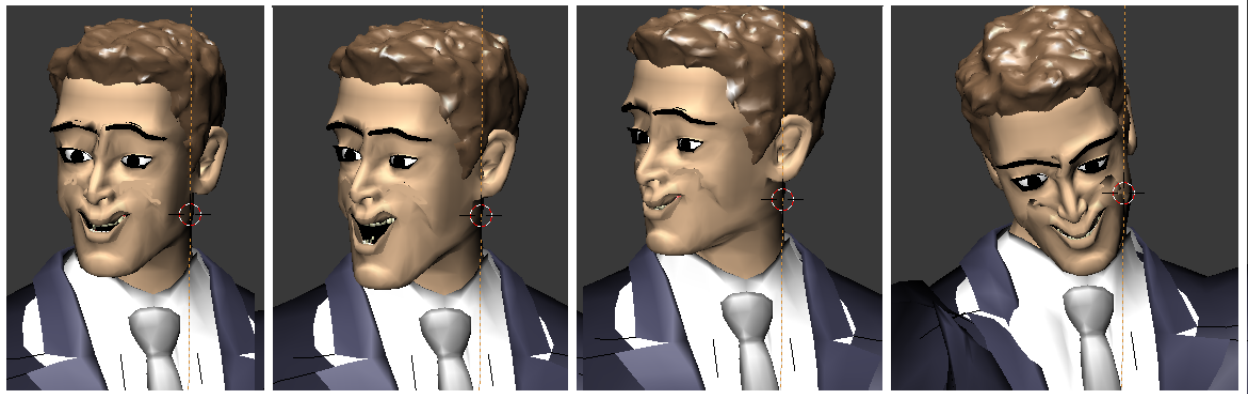


Figure 22. Design of speaking animations for the “Prince” character

4.2.1.3.3. Gesturing and other body movements

Some of the movements have already been mentioned during the description of the “speech” element. However, a believable character would usually use different, more complex gesturing cues during its speech or other actions. The shape of the character cannot perform any actions or movements by itself, and in order to make the character more realistic, it is highly important to implement the armature of this shape (Figure 23). This must be close to the anatomical structure of a real person: the more detailed the armature, the more believable the character’s animation will be. After this, each bone of the armature must be animated and synchronized with the context of the story. The last stage is the parenting of the armature to the textured shape.

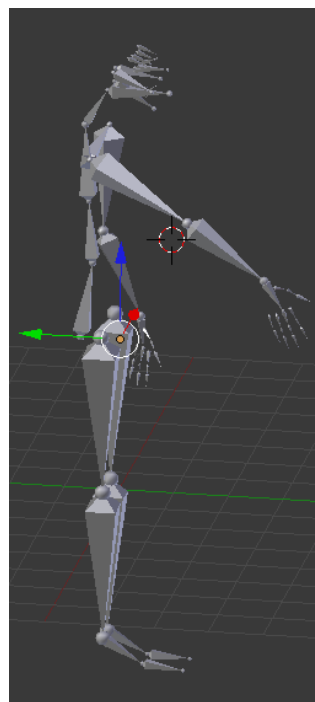


Figure 23. Armature, used for the character’s animation

Implementing the gesturing element is especially important to children with ASC in order to grab their attention. For example, if the character talks about the towers and says “*If you look up, you can see four towers*”, he must support this action by means of raising his head and pointing to the towers. When the stranger talks about the building, he must point to this building and look at it by means of moving his head. These visual cues during the characters’ communication can be considered the hidden elements of joint attention (Figure 24).



Figure 24. Prince looks up, down, and to the left when describing the castle

4.2.1.3.4. Emotions

A believable character must be able to express emotions that are relevant to the situation and demonstrate behaviour that one would expect in a real world task. The characters of VENECA display emotions with specific facial changes. For example, when the “Prince character” meets the main character, the face expresses smile and happiness. These effects were achieved as a result of detailed modelling of the face skeleton, which included bones for eyebrows, lips, mouth, cheek muscles and forehead. The happiness emotion was simulated by means of a smile and by raising the cheekbones. The wondering emotion was simulated by means of raising the eyebrows and slightly opening the mouth.

4.2.1.3.5. Social relations between characters

On a high level of the characters’ implementation, all the actions that the characters perform must correspond to the overall story of the game, and their relations must be clear and believable. For example, if the user is told that he has to meet his friend Sam, the

player would expect to see a greeting from Sam when he comes. If the user is told that Sam will follow him, this must be clearly presented in the animation. When the story supposes that the character meets the user for the first time, the character must introduce himself.

4.2.2 DESIGN DECISIONS CONCERNING HCI PRINCIPLES

Human-computer interaction plays a great role in the user's comprehension of the environment. Therefore, it is important to consider some of those principles. The main HCI principles that support usability can be divided into three main groups (Dix et al, "HCI", chapter 7.2):

- Learnability
- Flexibility
- Robustness

Each of these groups has specific principles that support usability. This chapter summarises design decisions made on the basis of the standard HCI principles according to these three main groups.

4.2.2.1 LEARNABILITY

Learnability usually refers to the ease with which novel users learn the system and reach the effectiveness of this use. Learnability itself is determined by several factors.

4.2.2.1.1. Predictability

Importance of the feature for HCI: Predictability is an important HCI principle, because it allows the users to make predictions about the results of their actions. Without this knowledge, it would be very hard to make any decisions when moving from one state of the system to another. Absolutely unpredictable systems usually generate a negative attitude in users, because they are not sure what response the system will generate from their actions.

Importance of the feature for children with ASC: Predictability is one of the crucial requirements for children with ASC, because any unpredictable situation or environment usually generates a feeling of stress in target users. At the same time, predictability is an excellent example of why HCI and other game requirements have to be analyzed along with user requirements, not separately. Predictability can be satisfied in two ways. One of

them is based on the process of generalizing and inferring from previous knowledge, which are definitely very important features for TD users. However, would this approach be a good design decision for VENECA? Recalling the problem with inference, mentioned in Chapter 3, children with ASC may not be able to predict or infer future states. Therefore, predictability for the target group must be achieved by means of giving them enough information at every step of the game and eliminating any necessity to infer this information from the previous steps.

Implementation of the requirement in the game design: In order to implement the predictability that would provide enough information at every point, the instructions that appear on the screen not only contain information about the task, but also display information about the results of these tasks. For example: “*When you come closer to the castle, the door bell will appear*”. When the door bell appears, and the user is required to click on it, the instructions also provides information about the result of the action: “*Press on the door ring to call the Prince*”. This approach allows experts to ensure that at every step the user is given enough information to make decisions. For the navigation task which is a continuous process, the instructions are presented on the screen during the whole navigation period in order to provide the required predictability.

4.2.2.1.2. Synthesizability

Importance of the feature for HCI: Synthesizability is an HCI requirement, which allows the user to see the effect of past actions on the current state of the system. This also allows the user to have a mental model of the game and observe explicit changes of the system’s states.

Importance of the requirement for children with ASC: Children with ASC, as “visual thinkers”, must always be able to observe the different states of the system. It is also important to ensure that all transitions between system’s states are visualized, because children with ASC are known to have weak verbal and inferential comprehension (see Chapter 3).

Implementation of the requirement in the game design: One of the major problems of the first prototype of VENECA was the lack of strong synthesizability. Some of the visual cues were provided when the character reached a location, including visual objects such as the door bell, tickets, door ring and question mark. The rewards signified a visual transition to the next part of the game. However, all these visual cues were not present on the screen

during the whole period of navigation, and there existed a risk that a user could forget the current state of the game.

4.2.2.1.3. Familiarity

Importance of the requirement for HCI: Familiarity has a direct effect on the system's learnability because it defines the number of functions that the user can intuitively guess, based on the previous knowledge or experience from the real-world. An ideal interface must be as familiar to the user as possible, even when the software itself is absolutely novel. An interface with different non-standard elements will require user to spend a lot of time learning new features and elements. However, the worst design can be observed when the interface includes some standard and familiar elements with an absolutely different meaning. For example, there can be a design where a *checkbox*-looking element is actually fulfilling the function of a *radiobutton*. This can decrease the predictability of the system extremely, and generate a feeling that the system is not consistent.

Importance of the requirement for children with ASC: The requirement of familiarity is partially related to agency, the importance of which for children with ASC was described in section 4.2.1.1.2, as they tend towards stereotypical thinking. However, agency considers only the part of familiarity related to the knowledge that children can transfer from their real-world scenarios and situations. As mentioned during the discussion about usability requirements (Chapter 3), children with ASC in the target age group usually have some experience of using computers, and therefore, their stereotypical knowledge of using standard interface elements must also be considered.

Implementation of the requirement in the game design: Some of the design decisions that are related to real-world based knowledge have already been discussed in section 4.2.1.1.2. In addition, different factors of users' familiarity with the standard interface were considered during this design stage. The game mode of the children does not suppose the existence of any GUI elements in order to avoid detracting too much attention from the main task. All the visual objects and instructions were integrated into the environment. The only interface element that has some correspondence to other programs was an "OK" button that was used in order to close different task messages or warnings (Figure 14). This is a widely used interface element that ought not confuse children.

4.2.2.1.4. Generalizability

Importance of the requirement for HCI: Generalizability is one of the features that allows the user to apply already achieved knowledge to other analogous situations. The more generalized elements the interface includes, the faster the user will explore the environment.

Importance of the requirement for children with ASC: While a generalizable interface is a very convenient and important feature of standard interfaces, generalization is one of the main challenges of children with ASC, as already discussed (see Chapter 2). One of the main motivations for implementing a highly realistic environment was that it would reduce the number of generalizing features. Children with ASC will be less likely to use this feature; moreover, actions that require generalization of previous knowledge may be problematic for the target users. Therefore, generalization was the first requirement that was not implemented in the game, since it contradicts the users' skills and requirements.

4.2.2.2 FLEXIBILITY

Flexibility refers to the a number of ways in which the user can achieve the same goal. There are five different features that refer to the system's flexibility. However, only two of them were implemented in VENECA. The first prototype included only one of them.

4.2.2.2.1. Dialog initiative

Importance of the requirement for HCI: This requirement refers to the method of communication between the system and the user. Highly flexible systems allow user to perform any actions in order to initiate response from the system at any time during the task. According to Dix et al (2004), such systems are "*user pre-emptive*". Moreover, the users are absolutely not limited in the ways of their input.

Importance of the requirement for children with ASC: Children with ASC usually experience difficulties in initiating communication with people (see Chapter 2). Therefore, for the fully user pre-emptive design, there could be a risk that the user will never initiate any dialogue with the system.

Implementation of the requirement in the game: Taking this information into account, for the fully pre-emptive system there would be a risk that a user will never initiate a dialogue with the system. Therefore, all dialogues which refer to the tasks are initiated by

the system, and the user responds to these dialogues by fulfilling the task, pressing the button or the icon. In addition, the sequence of tasks and the transition of the system from one task to another is non-flexible, and has a fully sequential order. However, in order to simulate real-world behaviour, the system includes one action that is mostly flexible: navigation. During navigation, the user can select any direction and angle, and rotate absolutely flexibly in space.

4.2.2.3 ROBUSTNESS

Robustness refers to a set of features that help the user to achieve the final goal. For example, a final goal of using text redactors is to produce a text document, and the system suggests different tools and settings in order to help the user. In VENECA, the final goal of the child user is to find all the locations, as was defined during the task analysis. In order to help the user to achieve this goal, several robustness principles were considered.

4.2.2.3.1. Recoverability

Importance of the requirement for HCI: Recoverability refers to design decisions that help the user to recover from errors. A system that does not allow the user to recover from his errors usually leads to the states from which there is no further transition. Such systems tend to block the user before achieving the final goal instead of helping him in his task, and are therefore not robust.

Importance of the requirement for children with ASC: Recoverability is a very important educational feature for children with ASC. As mentioned by Charman & Stone (2006), children with ASD enjoy constructive games which allow trials and errors. One of the challenges of children with ASC not being able to understand emotions is that they require observations rather than trials.

Implementation of the requirement in the game: The design of VENECA was planned as a less error initiative, because frequent errors may easily frustrate the user. Therefore, the objects that fulfil a particular function appear only at the moment when this feature can be used. For example, a user can call his friend only when he is near the hotel, by pressing on the door bell. If the “door bell” object was always present on the screen, the user would receive error messages every time when clicking on the object. In order to avoid this, the object appears on the screen only at the moment when it can be used in order to receive a reward. Such a design helps to reduce the number of errors (Figure 25). Additionally, for the road crossing task, the system automatically returns the user to his initial position in case he crosses the road at the red light (automatic recovery).



Figure 25. The door ring appears when the player comes closer to the castle

4.2.2.3.2. Responsiveness

Importance of the requirement for HCI: Responsiveness is a crucial requirement of robust software, because it helps to ensure that the system demonstrates some response to the user's action. Even if the user performs an incorrect action, he always wants to see a response from the system and observe any changes in the system's states. If the system does not generate any response to the user's actions, he can easily get upset with system. Moreover, another important feature of responsiveness is time stability: a badly-designed system may generate the responses too late, when a user has already forgotten about his action, moreover, the time for such responses must stay stable during the whole period of using the system.

Importance of the requirement for children with ASC: Children with ASC, as “visual thinkers” must always be allowed to observe the changes of the system's states in response to their actions. This is a very important aspect of their interaction with the VE.

Implementation of the requirement in the game: Returning to the problem with visual objects that could only be pressed near a particular location in order to initiate a response, in the previous section, it was mentioned that frequent error messages could frustrate children. Another possible design could make the icons present on screen, but generate no response until the location is found. This would be an example of a non-responsive design. Therefore, all the user's actions were modelled so that the user always receives the

system's response. It may be a change of the scene (for navigation keys), appearance of an error message (if the user obeys traffic rules), appearance of a visual object (if the user comes closer to the location) or appearance of a reward (if the user presses on the object).

4.2.3 DESIGN DECISIONS CONCERNING TECHNICAL REQUIREMENTS

4.2.3.1. Frame rate

The rate of frames refers to the number of frames running per second. When talking about computer video games that use extensive graphics, the most important aspect is their running speed. Most 3D games require installation of more powerful, game-oriented, graphical cards. For comparison, the most famous commercial game implemented in Blender, “Yo Frankey” (Figure 26) , uses different scenes in order to achieve the animation speed of 50 fps (frames per second) on a computer with an average video card. This approach allow unnecessary objects not to be loaded before the scene is called. The purpose of VENECA is users' navigation through the whole space, and therefore the approach of dividing the scene into different parts is not appropriate. Other non-trivial techniques were required in order to optimize the speed.



Figure 26. View of “Yo Frankey” game

One of the main factors that are able to slow down the frame rate is a large number of faces in model's objects. In modelling literature, such objects are called “*high-poly*” objects. “Yo Frankey” uses 40.000 faces in one scene. For comparison, there are 500.524 used in VENECA, and a lot of time is needed to load all these high-poly objects in the memory, and display them. Initially the number of faces was higher, and it required additional time,

to remodel high poly objects into low-poly ones. While, high-poly objects look more realistic, for objects, such as trees, which are used for the higher believability of the scene, and don't fulfil any important function, such simplification may not be significant. However, for objects, such as characters, it may have an effect on believability. Therefore, another approach has been used in order to speed up the game: once the visual characters appear on the screen and display some action, these characters are not hidden, but deleted, in order not to overload the memory. This was implemented by sending messages to character objects. Moreover, the screen has several animations of cars and traffic lights that run in an infinite loop: animations of cars and traffic lights which load the memory. At the moments when the user sees the rewards, the traffic lights are not observed, and therefore, it was decided to pause their animation for this period of time.

Additional optimization included the introduction of display lists that would store a large collection of frames. This feature speeds up the execution process and increases the frame rate. In addition, the number of animation updates was restricted to the optimal one. Moreover, some of the original textures were very large, which also resulted in a slow productivity. It was necessary to decrease the size of the pictures.

4.2.3.2. Platform dependency

Another technical decision concerns platform dependency. It is essential for experts and future developers to have a tool that can be easily transferrable and platform independent. As was highlighted in section Chapter 3, Blender has versions for Windows, Unix and Mac. And, in case future developers will want to modify the environment in Blender, they will not be constrained by a particular system. Moreover, Blender allows for saving the game in different formats, including executable (.exe) files, which can also be executed by the majority of operating systems.

4.3 FIRST PROTOTYPE EVALUATION

This section describes the details of the first prototype evaluation: participants, materials, procedure and results.

4.3.1 METHOD

4.3.1.1 Participants

Dr S.F-W took part as a research expert in the first prototype evaluation. The participant has a strong educational background in Psychology. The doctoral research of the expert was focused on the aspect of social attention in individuals with ASC. Her main research interests lie in the following areas:

- Different approaches (behavioural and cognitive) that are used for the investigation of typical and atypical behaviour of children and adults;
- Measures that can be used for clinical research of individuals with Autism Spectrum Disorder;
- Different types of social attention, such as visual attention or processing of motions and complex stimulus. The researcher is interested in these behavioural aspects in both children/adults with ASC and in typically developing children/adults.
- Interventions: her research interests lie in both computer-based intervention and education for individuals with ASD;
- Types of methodologies that can be used for investigation of joint attention in both typically and atypically developing individuals, such as eye-movement recording or change blindness.

As part of her postdoctoral research, Dr S.F-W participated in several research studies related to joint attention in people with ASC. When talking about computer-based technology for children with ASC, S.F-W was participating as a lead of the project which was based on development of computer game for teaching joint attention. The target user group of the project comprised children with ASC of a younger age group (3-5 years old).

4.3.1.2 Materials

A first prototype of VENECA, which included a completed 3D mode with traffic constraints and social type of rewards, was presented as software for evaluation. The actions, demonstrated in the game were presented in their logical order, without any interruptions, and included the following actions: a greeting message, instructions for the first task, navigation to the first location (the hotel), the first reward (meeting with Sam), the second task, navigation to the second location (the castle), the second reward (meeting with the Prince), the third task, navigation to the third location (a man on the opposite side

off the road), the third reward: instructions from the “stranger” character, the fourth task, navigation to the fourth location: the train station, the fourth and the final reward.

The demonstrated game was developed by means of Blender environment, but was run from an executable file, because this format was supposed to be used by future experts. The running speed of the game was 30fps. The demo was presented on an HP 4720s ProBook laptop with a screen size of 17.3 inches. The game ran in full screen mode with the highest level of brightness and volume.

The audio recording capability of Apple Ipod 4 was used to keep a log of the expert’s advices and analyze all suggestions after evaluation. Moreover, this approach economized the time for making notes during the evaluation process.

4.3.1.3 Procedure

The overall duration of the first prototype evaluation was 30 minutes. It was organized in the form of a non-structured interview, because at the moment when the first prototype was developed, the main purpose was to define some potential problems in the design that the expert could identify from earliest step. The current section describes the evaluation process in terms of its organization. However, it does not include the expert’s opinions and suggestions. This information will be presented in the sub-sequent section called “Results”.

At the beginning of the evaluation, the expert was asked for official permission to make an audio recording of the whole evaluation process and for the subsequent usage of this information as a part of the Master’s thesis. Only after Dr S.F-W had given such a permission, did the evaluation start.

The first step was a short discussion about the expert’s background, and experience in relevant fields. This information is crucial for further analysis of the participant’s authority, and the relevance to the discussed topic. The documented data achieved at this step has already been presented in section 3.3.1.1.

The next step was an introduction of the system by the developer. During this introduction, the expert was told that VENECA is developing as a research tool with a game as a cognitive element. The description of the target user group as children with ASC between 9 and 14 years old was also provided. Taking into account that at this stage the control panel and the other modes of VENECA were not developed, Dr S.F-W was shown a sketch

of the planned control panel with all the flexible options and features. The purpose of every feature in the game was also explained. Moreover, since the 2D cartoon mode has a modified cartoon scene, the expert was shown a sample picture of what the cartoon mode will look like. All this information helped to ensure that the expert will observe the demo version not as an independent game, but in the context of the main purpose of VENECA: as a research tool.

After this introduction, the demo of the game was launched. During this process, the expert was sitting in front of the laptop screen in a silent room, and could observe the demo in full-screen mode. During the demonstration of the game, the expert's observation was not interfered with any questions. She sometimes made notes about particular design decisions that need further discussion. Sometimes short notes were made by the author about the purpose of a particular feature and its potential meaning for the general goal.

After the demo was shown, Dr S.F-W was asked one question about potential problems observed that may affect the game's comprehension by the child users. During this discussion of potential changes, some additional questions about the expert's opinion of how the change must be implemented, and which approach for potential solutions would be preferable were asked by the author. The following section presents the results of this discussion.

4.3.2 RESULTS

4.3.2.1 Need for a main character

One of the main points made by Dr S.F-W was that the initial decision of not including the main character in the centre of the camera created difficulties during navigation. When a user wants to cross the road, he cannot see the border of the road because the camera is located at head level. This creates an additional challenge during navigation, because there is no explicit point of the user's representation in the environment, and the cursor that is also located at the same level as the camera is not able to resolve it. There must be another way to avoid this disorienting feeling. When talking about possible decisions, the expert mentioned, that introducing a character or an avatar that would be present in front of the camera would provide an explicit representation in the space. The expert was also asked about the probability of confusion that stereotypically thinking children may have if an avatar represents their appearance (as in the "*Is that really me?*" question discussed previously). The expert agreed that it might create additional questions in child users, and

made a suggestion for how the problem might be avoided. Instead of representing the main character as a user's avatar, it is better to introduce it as a character who needs the user's help in navigating. This approach might require a slight change in the initial game story represented. However it is the optimal way of introducing the character to the target user. Moreover, for the potential personality of the main character, Dr S.F-W felt that it might be useful to make the character more engaging, and assign him a personality that is different from the other characters, such as a robotic look.

4.3.2.2 Verbal remainder of navigation keys

The initial design of VENECA included navigational rules that are always displayed in the left corner of the screen. Taking into account the potential difficulties of the final target group with generalization and inference, a verbal reminder was also issued at every new task. Dr S.F-W mentioned that this design decision may be annoying for the users from the target group. She also mentioned that according to her experience, the duration between tasks is not long, and it is unlikely that children will need such a reminder, especially because the written instructions are always displayed on the screen. Moreover, instead of helping, frequent verbal reminders may interrupt the user's navigation task. Therefore, she suggested giving the error messages verbally only once, at the beginning of the game, because it is really useful in order to direct user's attention to the navigation rules.

4.3.2.3 Breaking down the tasks

The initial task presents information about control points, that the user will see on his way. The expert felt that it might be very difficult for the user to memorize so much information per task, and there was too much text displayed. Therefore, it would be more useful to subdivide this large task into sub-tasks. The user might be told that there are several control points on the way, and the first task could include information about only the first control point. When the user reaches this point, the instructions about the second control point would be displayed. This approach will structure the user's task and avoid the need to memorize too much information at once.

4.3.2.4 Visual support of the locations

Dr S.F-W suggested that instead of text reminders on the sidebar, which users will be less likely to read during the task, it is better to associate every location, including the control points, with a visual object that corresponds to that location. These objects may be located on the sidebar. Once the character reaches a location, these visual icons may be placed on the sidebar, accompanied by a particular sound effect, which will create a feeling of “collecting locations” (the term used by Dr S.F-W). This approach may also be used as a reward in the non-social mode. Moreover, it provides a more comprehensive reminder that attracts more attention than the plain text. When asked about the nature of visual icons, and whether it might be reasonable to introduce pictures of the real buildings, the expert mentioned that the better decision would be to keep these icons abstract, but still related to the location. As an example, she mentioned that a guitar could be associated with a “music shop” location. This approach will make the game more engaging for children, and create a feeling of collecting these objects. When an demonstrator has asked the expert’s opinion about the probability that children will be able to connect these abstract pictures with real buildings, or whether it would be better to use pictures of buildings with abstract objects in front, the expert suggested that it might look very confusing for children, and well-selected icons will most likely be descriptive enough for children.

4.3.2.5 “Navigator effect” or map

As an addition to the current features, the expert mentioned that at the highest level of the task, a potentially useful feature might be a map. It could present the simplified upper view of the city, and display the user’s current location by means of a moving point, as is done in modern navigators. This will teach the child how to abstract from his current location seen on the screen to the map and back. It might also simplify the user’s task. In addition, this feature can be made flexible and also be used as a separate goal in experts’ studies.

4.4 DESIGN OF THE SECOND PROTOTYPE

4.4.1 Design of the game element

In this section, the results gained during the first prototype evaluation are analysed in terms of their importance and suitability according to both believability and HCI criteria.

Following this, the way in which particular suggestions were implemented is described. Moreover, the implementation of additional game modes is described.

4.4.1.1 INCLUSION OF THE MAIN CHARACTER

4.4.1.1.1. General analysis

Returning to the “*cyborg’s dilemma*” (section 4.2.1.2.2), it was initially decided to use a cursor as a preliminary design decision, and seek further support from the expert. This initial decision was justified by the fact that the main character will not allow the comprehension of the environment from the user’s point of view. Therefore, it might be more believable not to introduce the avatar. However, the problem mentioned by the expert is crucial for the navigation task, and it might be difficult for the user to make decisions when there is no explicitly displayed embodiment of the user in the space. A decision to introduce a main avatar as a game character which needs assistance in navigation, as suggested by the expert, helps to avoid the problem of the cyborg’s dilemma. Another suggestion by Dr S.F-W, about assigning the main character a distinct personality, such as robot, also has a reasonable support by the literature. In this area, there are many examples of how mobile robots are able to assist children with ASC. Such robots are often used in different therapeutic or research studies. Keepon, a creature-like robot, was used in the study by Kozima et al (2007) in their therapeutic studies of sharing social information, and is a good example of how robotistic characters are appreciated by children with ASC. In another analysis of robot-assisted therapy, Ricks et al (2010) mention many studies that demonstrate positive behaviour being observed in children with ASC when communicating with robots compared to that during their communication with peers, teachers or therapists. The authors also highlight a potential in future for robot-assisted therapy for children with ASC. Such robots appear to be very engaging for children from the target group. Taking this information into account, it is possible to assume that children with ASC will most likely be happy to assist a robot character during its navigation.

4.4.1.1.2. Decision made

It was decided to include a robot-like looking character, called Andy, into the game (Figure 27). Taking into account the discussion above, this design decision must be useful both for navigational purposes, and for the children’s motivation to assist the character. However, it also required a slight change in the initial story. In the second prototype, the robot

character was presented as the one who needs to visit all the locations and meet with all the characters in the game. The design of Andy was also justified by different requirements.

4.4.1.1.3. Believability

4.4.1.1.3.1. Agency

The decision to introduce a robot as a character that needs help in navigation looks very agent, because robots are usually known to be electronic creatures that can be manipulated. In addition, the story required a slight modification. An additional improvement achieved by introducing a main character, which was overlooked during the first design, is that it now becomes possible to visualize the “*following*” activity. When the main character reaches the location and calls his friend, the scenario suggests that they will explore the city together, and the system says: “*Sam will follow you*”. In the previous version, the user saw Sam running in the environment. However, this design decision was not agent, because in fact it didn’t display Sam following another character. What the user could observe was Sam moving beyond the camera rather than following the user. But the introduction of Andy allowed to achieve agency for this task: the user can now observe two characters on the screen, one of which is Andy, and the second of which is Sam, who moves slightly behind the main character (Figure 28). Additionally, a global change was required in switching between the character and the camera. Previously, the traffic constraints and sensors detecting nearness considered the camera’s location. However, in case the user sees the character navigating the street, Andy becomes the focus of navigation. If the game still contained sensors for the camera’s location, all the error messages or rewards would appear with a slight delay, when Andy had already passed the location, and this would contradict the agency rules. Therefore, during the navigation process, keyboard keys are sending signals to Andy and the sensors are also detecting the robot character.

4.4.1.1.3.2. Appearance

The robot character was designed in the same way as other characters, but the body parts were made to look more robot-like, using different cylindrical and square elements. The robot also has eyes which can rotate when the gazing effect is needed. In order to make the robot more engaging, different elements were coloured yellow and green.



Figure 27. Introduction of Andy by the system

4.4.1.1.3.3. Gesturing and other body movements

Like the previous characters, Andy was animated. This was implemented by creating the robot's armature. However, as a main character, Andy required more than one animation. Therefore, three main animations were implemented: animation where Andy is greeting the user (Figure 29), animation of the walking character (Figure 30), and animation where the main character says goodbye to other game character (Figure 31).



Figure 28. Sam is following Andy on his way to the castle

4.4.1.1.3.4.Speech

It was important to assign Andy a voice which would sound very robotistic. Such a voice was integrated as an add-in to the used TTS system. The first attempts to adjust the voice, sounded very unclear (even though it was possible to understand it, children with ASC would have found it problematic). However, by reducing the pitch and the speed of the robot's speech, it became possible to make the voice more clear.

4.4.1.1.3.5.Communication with other characters

It was important to ensure that all types of communication were re-designed as a communication between Andy and the character, rather than a user and the character. Moreover, Andy, as character which communicates with the user by means of navigating, also needed to greet the user. This action was implemented at the moment when the system introduces Andy (Figure 27, Figure 29).

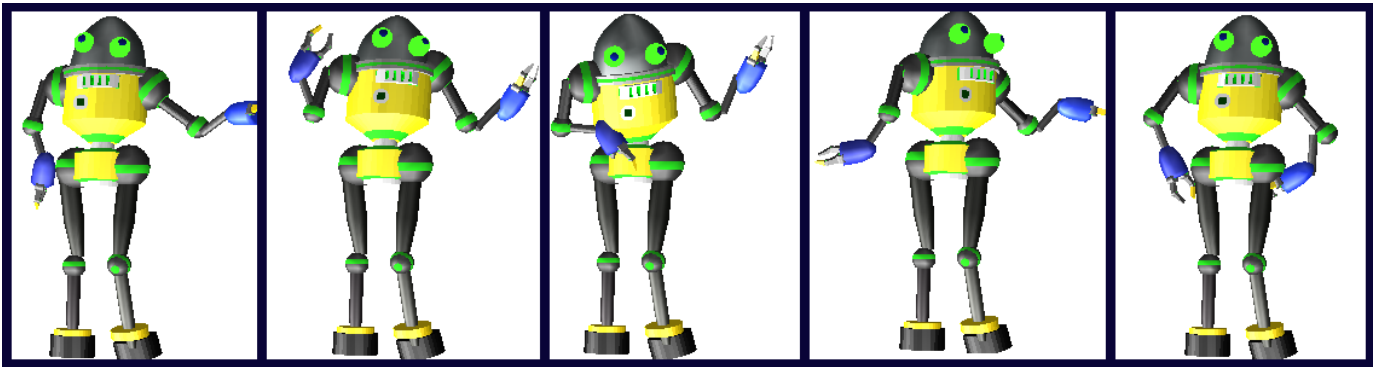


Figure 29. Screenshots of animation when Andy is greeting the user

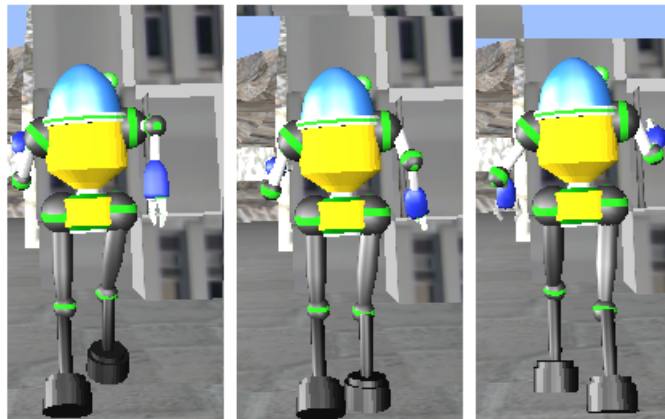


Figure 30. Walking animation of Andy

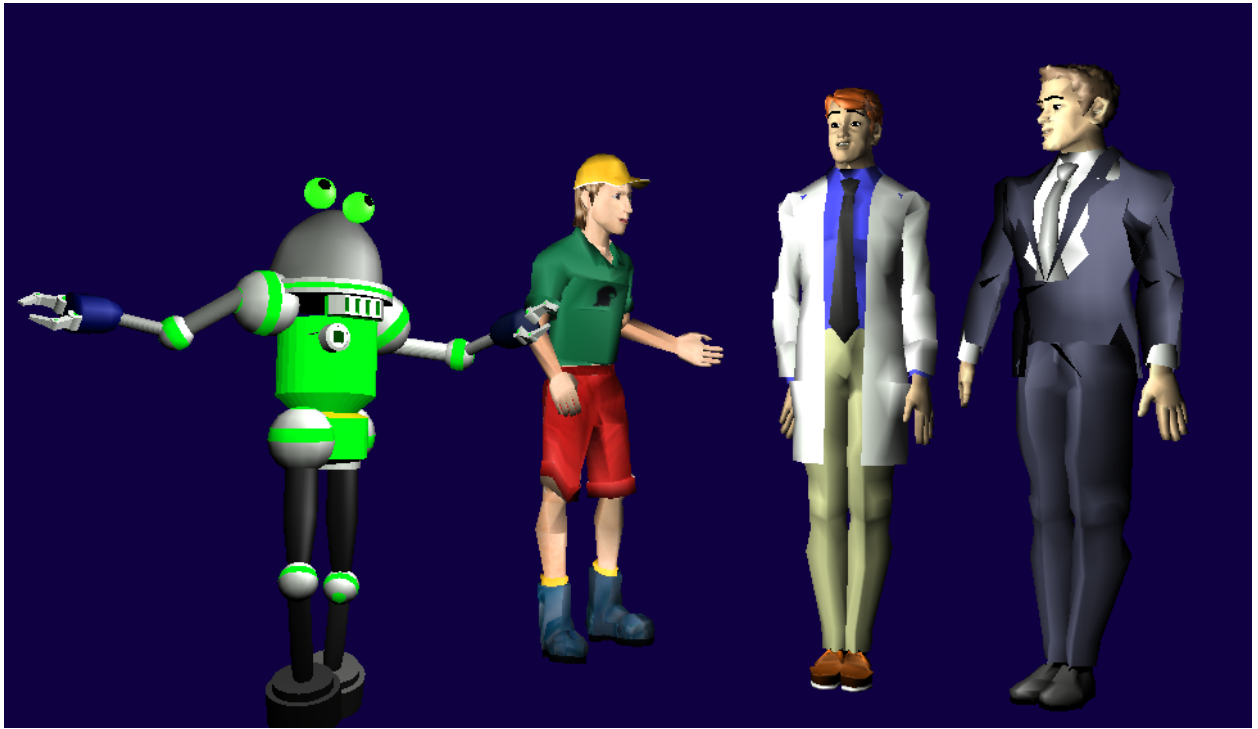


Figure 31. Animation of Andy, when he says “Goodbye” to the user and game characters

4.4.1.2 DIVISION OF THE MAIN TASK AND INCLUSION OF THE VISUAL ICONS

Recalling previously mentioned information about children with ASC being “visual thinkers” and their tendency to think in pictures rather than via text, it may be easier for them to observe the images on the sidebar rather than text, since such icons will attract more attention. Moreover, such icons could help to divide the task into sub-tasks. Therefore, it was decided to follow the expert’s suggestion and implement visual icons, and use the sidebar for these icons. However, several factors had to be considered during implementation.

4.4.1.2.1. Believability

- **Agency**

It was important to ensure that the visual icons represent objects that are associated with a particular location. The following design decisions were made at this stage: coins and money represent the bank building, the guitar is representing the music shop, the shopping basket is representing the shopping centre (Figure 32), cartoon images of the hotel and the castle represent hotel and the castle correspondingly, a caricature of a man represents a stranger on the road, and a train represents the train station.



Figure 32. Andy passes the shopping centre. The icons on the sidebar: the city bank and the shopping centre are reached (colourful icons), and music shop and hotel have to be reached (black and white icons)

4.4.1.2.2. HCI

- **Synthesizability**

As discussed in the previous chapter, synthesizability may be one of the problems of the current design. Because the users are not able to see the effect of their actions during the navigation process, neither they are able to explicitly observe transitions from one state to another. The decision to use visual icons that appear on the screen when a particular location is reached suggests an excellent solution to this problem. However, this requires a detailed justification. First of all, it was important to understand how the icons will be presented on the screen before Andy reaches the associated location. The simplest way is to keep a sidebar with empty places for icons, which would appear at the moment when the character reaches the location. However, this decision was not optimal specific needs of the users, because the icons are supposed to be visual reminders. Therefore, it might be more useful for the user to observe them during the whole navigation process. The icons being present on the sidebar during all the time, allow users to see what locations must be reached in the future. However, this creates another issue: how to make the transition process visible in this case? In order to satisfy both requirements, it was decided to display all the visual icons in black-and-white before the locations are reached. At the moment

when the location is reached, in order to make the transition process more obvious and engaging, a big icon is displayed in front of the camera, in a couple of second it disappeared, and the same icon on the side bar lights up in coloured form (as if it was “picked” on the sidebar) (see Figure 32). This process was also accompanied by a “magic” sound.

- **Predictability**

In order to make the icons appearing at every location as predictable as possible, each task used an initial image of the icon and a picture of the real building associated with it (Figure 33). Moreover, decision of making the icons visible all the time (described above) implemented sufficient predictability at every moment of playing the game.

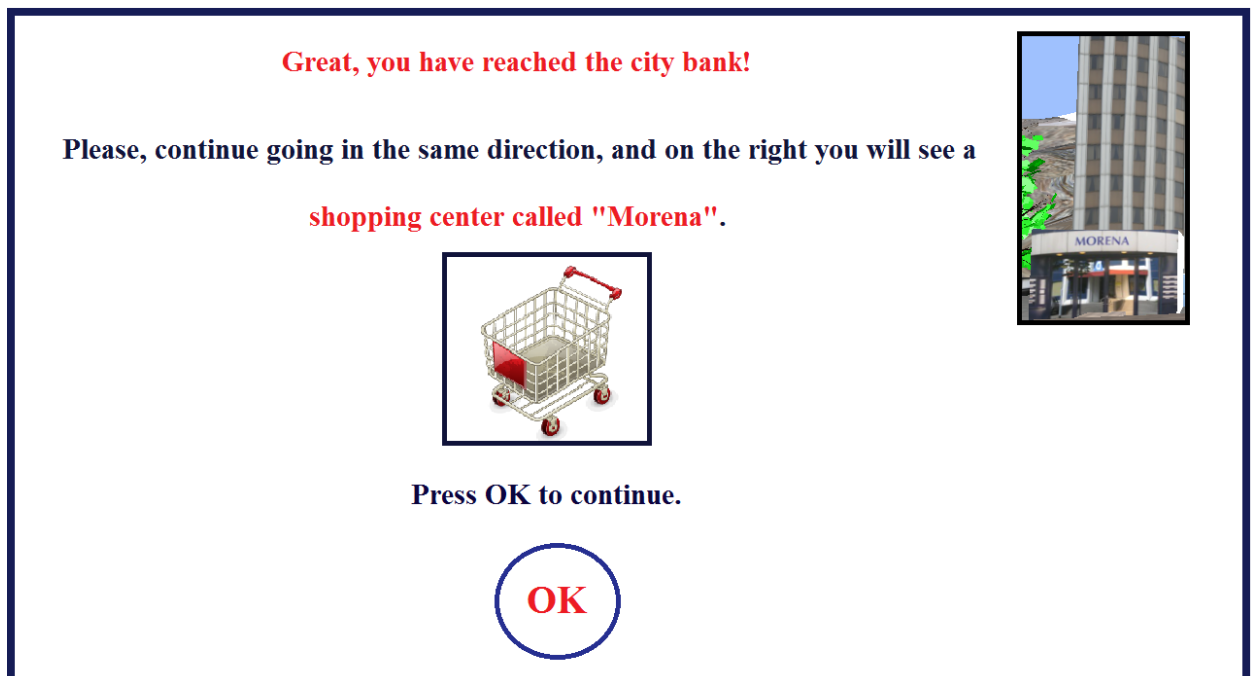


Figure 33. Implementation of predictability. The task displays the images of an abstract icon and an associated building

4.4.1.3 VERBAL REMINDERS OF NAVIGATION RULES

When analysing this suggestion, no literature was found to support negative effects of frequent reminders on children. However, since this modification is not costly, it was decided to make the change suggested by Dr S. F-W and ask the future experts' opinions about this design decision.

4.4.1.4 NAVIGATOR

The introduction of a map was mentioned by the expert in this prototyping stage as a potentially useful add-in. However, this couldn't be prioritized over the main design steps of the game. Moreover, implementation of such an instrument might be technically difficult, because it would require an additional overlapping scene, and the sending of messages between them in order to display the character's location in real time. Taking into account the processing speed of the existing scene, running two scenes at the same time might require a stronger graphic processor. Therefore, it was decided not to implement this suggestion until more information from other experts was gained.

4.4.1.5 IMPLEMENTATION OF THE NON-SOCIAL 3D MODE

The main differences between the social and non-social tasks are the rewards that the user observes when the sub-tasks are completed. In the social mode, the user meets with different characters, and for the non-social mode, it was important to implement other types of rewards that would be strictly non-social. At the same time, the task still needed some story and motivation for the user. The idea of using visual icons suggested a good way to achieve the required effect: during the non-social task, instead of collecting the icon and meeting with the character, the user would be rewarded only by gaining the icon. The task was also modified, so that the user is told that Andy is visiting the city and wants to see a list of locations, instead of meeting with his friend. During the final reward, only Andy thanking the user was presented (without other characters). Additionally, minor modifications described below were required in order to make the task consistent.

4.4.1.5.1. Believability

- **Consistency**

Additionally, the locations that are introduced as control points during the social tasks, were made independent tasks in the non-social mode. The reason for changing these intermediate points into independent tasks is based on the consistency requirement: the social rewards that the user observed in the social mode were absent in the non-social mode, and for all the tasks the user received identical rewards. Therefore, division of these absolutely analogous tasks into main and control points would not be consistent, because for the main tasks the user would wait for other types of rewards. Moreover, it makes the two modes absolutely comparable with each other. In order to implement this, all the locations were presented on the sidebar at once (previously, only the locations referring to

the current sub-task were presented). Now the users had the full picture of all the locations that must be visited initially (Figure 34). Moreover, as long as the control points were modified into independent locations, it was important not only to pass these locations, but also to come near in order to collect the icon as for all other locations in order to make the tasks consistent. This also required more precise instructions for all the control points and implementation of other kinds of “near” sensors.



Figure 34. Non-social task. All the icons are presented at once. The stage when the first four locations are reached.

4.4.1.6 IMPLEMENTATION OF THE 2D REALISTIC MODE

The second prototype also included the 2D realistic mode. It inherited the task structure and design decisions from the 3D mode, as described in the previous sub-sections above. This was an important requirement, because otherwise two believability levels could not be compared with each other. The current section describes the design decisions that made the system less believable. It was designed by means of rendering the 3D mode into flat pictures and putting these pictures in front of the screen. Unlike in the 3D mode, the user could only navigate left and right, because, 2D mode does not provide depth in the scene. Moreover, for the same reason, the rotating keys were switched off. This required a slight

modification of the initial navigation rules (Figure 35). The visual icons, implemented for the second prototype, were also included in the 2D mode. The game characters were presented as flat avatars. Another difference was that 2D mode didn't include traffic constraints, because the flat images did not allow simulation of the road crossing behaviour. All this information suggests that the main differences between the 2D and 3D modes were the absence of the feeling of navigating in the space and the absolute static behaviour of all the characters and objects.

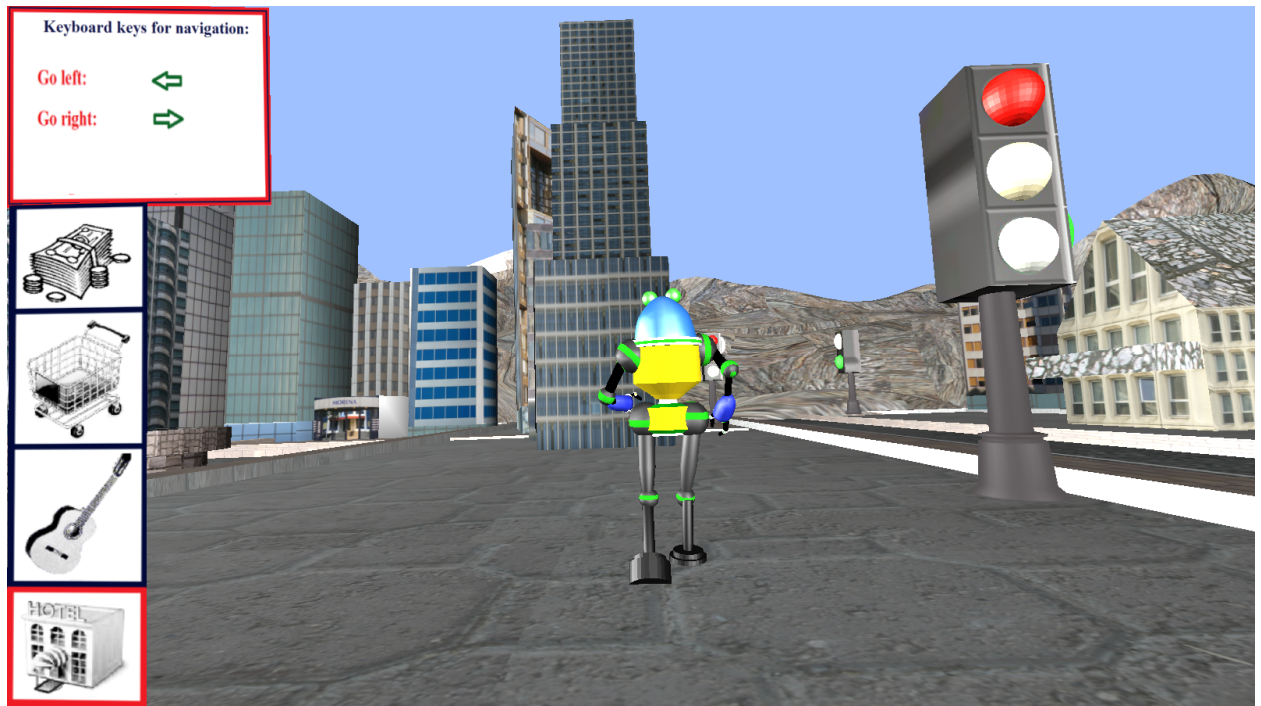



Figure 35. 2D realistic mode. The navigational directions were reduced to left and right

4.4.2 Design of the experts' interface (control panel)

The second prototype of VENECA already included a control panel where all the flexible features could be adjusted. As long as there are no specific user requirements for the experts' interface, it was analysed based on the classical HCI principles. Development of a control panel that would correspond to all HCI principles using Blender was initially a challenging task, because this modelling tool does not include standard GUI elements. Implementation of this panel using another programming environment was not possible, because it had to send messages to the main scene, and there is currently no integrator of Blender with other programming environments. Therefore, this task required non-trivial design decisions in order to make the interface as close to the standard one as possible. Figure 36 represents the view of the control panel developed at this stage.

Welcome to VENECA (Virtual Environment for Navigational Education of Children with ASC)



Please, specify the options for all the game features:

Instructions:

Delivered in a verbal form: ☐

Delivered in a written form: ☐

Type of rewards for the completed steps :

Social: ☐

Non- social: ☐

Traffic constraints during road crossing:

Display error messages: ☐

Don't display error messages: ☐

Character's walking speed

Slow: ☐

Medium: ☐

Fast: ☐

The level of the environment's believability:

Realistic 3D mode (highest level): ☐

Realistic 2D mode (medium level): ☐

Cartoon-looking 2D mode (lowest level): ☐

START

Figure 36. Control panel for experts, implemented during the second iterative design

4.4.2.1. Learnability

4.4.2.1.1. Familiarity

One of the main challenges of the control panel was to make it familiar to the user. As was already mentioned, the standard GUI elements are absent in the Blender environment, and therefore, another technique for making the interface familiar to the user was invented. The *button*, *group boxes*, *radio buttons* and *checkboxes* were simulated by means of drawing analogous shapes for these elements (Figure 36). However, it was also important to simulate the effect of “selecting” the option, so that the user could observe the change.

This was performed putting the “plane” elements with the pictures of the “tick” and red square signs into the selection areas of checkboxes and radiobuttons correspondingly (Figure 37). Initially, these were hidden, but when clicked on this area, the images became visible, as if this was a usual GUI element. However, in addition to the visual familiarity, it was important to implement functional familiarity that the user would expect from these elements. For example, the representation of the task can be both written and verbal at the same time (these features are not exclusive, as was mentioned during task analysis, Chapter 3), and therefore it was important to put an appropriate *checkbox* element near these two options. At the same time, the rewards can be either social or non-social, therefore, the exclusive *radiobutton* element was placed near these options, and it was important to ensure that when one of the exclusive options in the group was selected, the other are switched off.

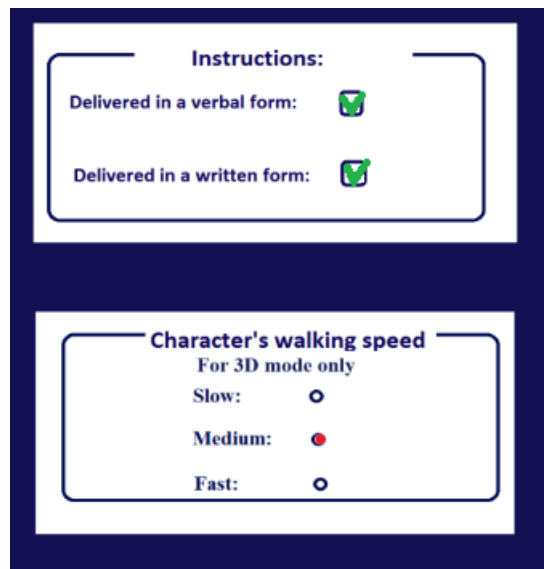


Figure 37. Simulation of the selection process in VENECA's control panel

4.4.2.1.2. Synthesizability

As mentioned during the task analysis (Chapter 3), 2D modes do not support changes in navigation speed and traffic constraints. Therefore, when the user selects the traffic constraints, the navigation speed automatically switches to the medium value, and the traffic constraints are turned off. The potential problem with this design is that the user would not notice this change in the system's state and expect the game to display the previously selected options. Therefore, warning messages, informing the user about the change, were implemented (Figure 38). They allowed more explicit visual support of the change in the system's state.

For this level of believability, the speed and traffic constraints were set to default values.



Figure 38. The warning message used in order to grab attention to the system's change

4.4.2.2. Flexibility

4.4.2.2.1. Customizability

When discussing about the flexibility of the game during the design of the first prototype, it was mentioned that there exist two flexibility features that will be implemented in this game, and only one of these was included in the first prototype. Customizability is another feature that defines the game's flexibility. It refers to the possibility of adjusting the system to the particular needs of the user. The control panel is a tool that allows experts a high degree of customizability. When discussing the control panel earlier in this thesis, it was mentioned that, unlike in other research games which are strictly adjusted to a particular study, VENECA allow experts flexibility in the selection of different modes. Moreover, when talking about customizability, experts also have a potential to adjust the system to the needs of a particular child. For example, a child with slow motor skills may require the slowest navigation speed, and a child with highly impaired verbal comprehension may require written tasks to be presented all the time. To sum up, the control panel suggests customizability for both the expert's and children's requirements.

4.4.2.3. Robustness

4.4.2.3.1. Responsiveness

The control panel was implemented so that every user's click on the control element generates the system's visual response. A potential situation which required additional implementation was the action of clicking the "start" button. As was mentioned during the task analysis, the game can be launched only in case all the game features are selected. However, there might be an instance, when the user disregards the initial task, and presses the "start" button when not all the game features are selected. In case the system does not generate any response at all, the user could easily consider the system non-responsive. In order to avoid this, the error message was generated.

4.4.2.3.2. Recoverability

As mentioned, the user can sometimes make errors in selecting different modes. In case the user presses the “Start” button before selecting all the options, he can easily recover from this error by clicking the “OK” button and selecting the remaining game features. Additionally, there may be instances when the user has made incorrect choices, and wants to change the already selected option. Therefore, the system does not fix the first choice, and allows full recovery from potential errors for an unlimited number of times. The user can easily change his initial choice: in order to deselect the undesired “checkbox” element, the user needs to press on it for the second time; and in order to deselect the undesired “radiobutton” option, the user is required to select another “radiobutton” element in the same group; according to the features of these elements, the first option will be automatically turned off.

4.5 SECOND PROTOTYPE EVALUATION

This section describes a process of the second prototype evaluation: the participants, materials, procedure and the results.

4.5.1 METHOD

4.5.1.1 Participants

Evaluation feedback during the second prototype evaluation was provided by Dr S.H. This expert has stronger background in software development, rather than in psychology and cognition, compared to the previous expert. His experience in software development is very relevant to this thesis, because most of the games are oriented for children, either TD or children with ASC. The major research focus during his doctoral study was the development of story maps: an application that could flexibly generate various stories for children. Dr S.H. was the lead programmer in a project focusing on communicational education of children with ASD between 3 and 5 years old. In addition, the expert has experience of developing 3D environments: one of the projects that Dr S.H. participated in was related to the development of autonomous characters in more simplified 3D environments, their arbitrary navigation and route planning. A screenshot of this project can be found in Figure 39. The current project of the expert was related to the development of web-applications in Python, a programming language that was used for the development of VENECA.

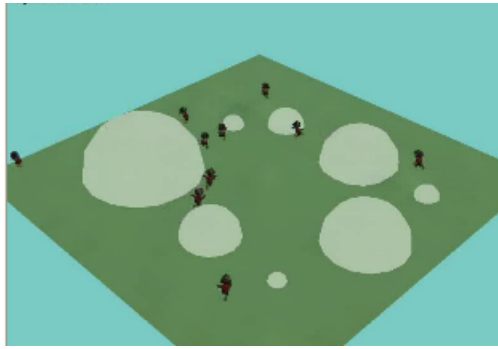


Figure 39. Navigation of characters in 3D environments, developed by Dr S.H.

4.5.1.2 Materials

The second prototype version of VENECA software was used as a main material during the second prototype evaluation. This version of the game included the following features:

- 1) A completed 3D mode for social scenarios with Andy as a main character;
- 2) Sidebar, including visual icons for every location;
- 3) A completed 3D mode for non-social scenarios with Andy as a main character;
- 4) The less realistic 2D mode with rendered pictures instead of 3D space;
- 5) A control panel for experts.

Returning to the general goals of VENECA, the only mode that the second prototype of VENECA didn't include was the least realistic mode with cartoon-like images.

As during the first prototype evaluation, the demonstrated game was not running from the developing environment, but from an executable file, as this is supposed to be the running mode used by future experts. The running speed of the game was 30fps. The demo was presented on an HP 4720s ProBook laptop with screen size of 17.3 inches. The game was running in full screen mode, with a highest level of brightness and volume.

The audio recording capability of Apple Ipod 4 was used in order to log the evaluation process.

Additional material that was included into the second evaluation, was a set of semi-structured interview questions. At this point, VENECA included the majority of features, and it was important to clarify some specific questions concerning the existing design. All the questions in the list were designed in an open-ended manner. This design decision was motivated by the fact that such questions would extract more information from the expert,

rather than limiting him with pre-defined answers. The majority of the questions were delivered in a form in which it is not possible to answer “yes” or “no”. However, for those questions where a “yes” or “no” answer was a possibility, subsequent related questions asking for additional explanation and justification of the response were designed. All the questions were designed to be non-leading, and to not express the author’s opinion, in order to obtain the more objective feedback. These questions were designed prior to the evaluation process. The set included 18 questions regarding the game element of the software and 19 questions regarding the experts’ panel. These questions were ranked according to their priority prior to the evaluation process, in case the time limit meant they could not all be asked.

4.5.1.3 Procedure

The overall duration of the second prototype evaluation was 40 minutes.

As during the first prototype evaluation, official permission for making an audio recording of the whole evaluation process and subsequent use of this information as a part of the Master’s thesis was requested from the expert. After Dr S.H provided his permission, the evaluation process started.

During the first step of the discussion, Dr S.H. provided information about his experience in relevant fields, his research interests, and his educational background. The recorded information was presented in section 4.5.1.1.

The next step was the introduction to the system by the developer. Unlike first prototype evaluation, the second version of VENECA already included the control panel, and it was important to evaluate the intuitiveness of this panel. Therefore, compared to the first evaluation process, the expert received a smaller amount of information, which was sufficient for a very general introduction of the system. This information was pre-designed as a part of the interview design. The full quote of VENECA’s initial introduction as it was delivered to the expert is presented below:

“The given software is a research tool with a game element. The game is presented as a Virtual Environment which displays a part of the city. The main task is based on navigational education, but there are some other educational goals that will be discussed later. The target user group are children with ASC between 9-14 years old. This tool provides research experts with the possibility of flexible

selection of different desirable features. This is the control panel which was designed specifically for this purpose”

After this introduction step, the demo of the game was launched. The process of the second prototype evaluation was slightly different from that of the first evaluation, because it was strictly divided into two parts: evaluation of the experts’ control panel and evaluation of the game element. The expert was initially informed about these two main steps, and then, the evaluation of the control panel began. During this process, the expert was presented with a control panel with no any specific information provided. Following this, he was asked a number of questions the main purpose of which was to learn about his expectations from the presented systems and his understanding of its functionality. The questions asked during the evaluation of VENECA’s control panel are presented below:

- 1) What do you think about the idea of grouping the options according to different game features?
- 2) Given the name of the software, could you guess its main purpose without any introductory information?
- 3) From your point of view, what is the purpose of introducing square or round elements near options? What are the differences between them?
- 4) What response from the system would you expect in case you didn’t specify any option for one of the features and pressed the “Start” button?

Given a set of game features could you specify for any of them:

- How do you understand the purpose of this feature?
 - What study could you make using this flexible feature?
- 5) Do you think, there are any game features that can be exclusive?
 - 6) What do you think will happen to the “navigation speed” feature in case you have selected the 2D (either realistic or cartoon-like) mode? Will it still be active? If yes, please, specify the way that you expect it to function in the game.
 - 7) What do you think will happen to the “traffic constraints” feature in case you have selected the 2D (either realistic or cartoon-like) mode? Will it still be active? If yes, please, specify the way that you expect it to function in the game.

After that, the system was adjusted to the following features:

- Both verbally and non-verbally delivered tasks were specified;
- The most realistic 3D mode was selected;
- The type of rewards was adjusted to social;

-
- The traffic constraints were turned off;
 - The speed was set to the medium level.

When the selection process was finished the game with selected game features was launched. Unlike the first evaluation process, the demonstration of the game was interrupted by questions from the developer that were related to a particular part of the game, and were discussed during the demonstration process. The list below displays all the questions that were asked during the demo of VENECA's game element:

- 1) What advantages of making the messages manageable by children (users) compared to the automatic proceeding to the next step can you mention? Might there be any benefits of the opposite approach? Could that affect the level of the system's unpredictability and cause the same stress as in real-world tasks? Could it decrease a feeling of control of the system?
- 2) Please, specify your opinion about colours of the VE.
- 3) Currently, the verbal representation of the navigation keys is displayed only once, at the beginning of the game. It was suggested during the first non-formative prototype evaluation. Please, specify the benefits or shortcomings of this approach for the target user group.
- 4) What do you think about an idea of introducing the real-world task not in the context of "*you have to do this*", but in the context of the scenario, with game story and purpose? Do you think that might motivate children? What disadvantages of this approach can you mention?
- 5) What is your opinion about the idea to introduce the icons, such as doorbell, question, and tickets only when the child reaches the location? (Error-prevention question) In case, they would be visible all the time, what is a probability that frequent messages with errors would disappoint the user of the target user group? What do you think could be an advantage of another design? Do you think, in case the system could count errors, you could use this data for comparison of modes?
- 6) What do you think about social communication with characters which is presented in a form of a reward? In which way can it affect their attitude towards social communication?
- 7) The elements of interface are mostly integrated into the environment. What do you think about an idea of introducing the graphical representations of locations? Do you think that all the locations on the sidebar must to be visible during the navigation

(even remaining white-and black for the unreached locations)? Do you think it will be intuitively understood by children with ASC that the next destination is the one which is white-and black following upside down?

- 8) What is your opinion about default keyboard keys used for navigation?
- 9) What, from your point of view, are advantages or disadvantages of introducing the main character for the navigation task?
- 10) Do you think, there any advantages of 3D environments when the task is based on navigation for children with ASC?
- 11) Do you think the skill of asking for directions from other people will be helpful for children with ASC?

4.5.2 RESULTS

This section describes the answers to all the questions mentioned during the procedure of evaluation.

4.5.2.1 EXPERT'S INTERFACE

- 1) The expert's opinion about the decision of grouping the icons was positive. He mentioned that it provides him with a general idea about the system's purpose and game elements;
- 2) The overall impression about the welcome message and the intuitiveness of the interface was also positive. He mentioned that the options look very descriptive, and the title of the game provides enough information about the purpose of the game. He also specified some features that can be seen by looking at the interface: there must be some character that can walk, and there will be road crossing task with guiding instructions in the game.
- 3) When asked about the purpose of including two kinds of options: square and written, the expert could easily guess that square options allow selection of both of them at the same time, while the round options require selection of only one of them.
- 4) When asked what he would expect from the system if some of the features were not specified, Dr S.H. mentioned that he can see from the interface that there are no default settings, and so, he wouldn't expect the system to run until all the features are specified.

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- 5) When asked to specify several probable studies, the expert mentioned an example of a study that could compare verbal and written instructions.
 - 6) When asked about exclusive game features, i.e. some options that exclude the existence of another option of another game feature, Dr S.H. stated that all the options look quite independent. This evidence could generate difficulties in understanding the interface, because at the moment of prototype testing, there were two options, walking speed and traffic constraints, that were not implemented in the 2D modes (neither realistic nor cartoon).
 - 7) When asked about the traffic constraints in the 2D mode, he supposed that the traffic constraints will be simulated in terms of text error messages. He also specified that where the front view of the road is presented, he would expect to see the traffic light either as an interface element or as a 2D-animated element in its correct place. Moreover, he stated that he would expect the cars to move in front of these traffic lights. This means that the expert would expect a 2D mode to still have dynamic traffic constraints.
 - 8) However, when asked about the moving speed of the character, the expert said that these options, in his opinion must be exclusive.

To sum up, the expert wouldn't expect all the dynamic elements to be transferred into the 2D mode: some of the elements, such as cars and traffic lights could be dynamic, while the character's navigation was expected to be static.

4.5.2.2 GAME ELEMENT

- 1) When asked his opinion of messages that are fully controlled by the user, Dr S.H. mentioned that the instructions contain a relatively large amount of information. And more time might be required for participants to read them. Moreover, at the moment when the instructions are verbally presented, the participant might not be attentive enough, and may require more time to read them again.
- 2) Concerning the suitability of the colours for the target user group, the expert mentioned that the game in the realistic mode looks quite colourful and will probably be engaging.
- 3) When asked his opinion concerning the verbal representation of the navigation keys: whether or not it might be useful to repeat it for every task, Dr S.H mentioned that it may be enough for the user to see this message only once, when the first task is

presented. In case the navigation keys are forgotten, the user can always refer to the written reminder in the corner of the screen.

- 4) When asked about the inclusion of story in the game scenario, the expert mentioned two potential opinions about this approach. The first one was that a game with a social story may appear to be more engaging, and might increase the motivation to fulfil the task. However, he also specified some potential risks of such an approach: it makes the game more complicated, and therefore, a user has to memorise more additional information.
- 5) When asked about his opinion about presenting particular visual objects only when a character reaches the location, i.e. when they can be used. He stated that this might be a good decision, since it avoids error messages.
- 6) Concerning the idea of presenting social communication as a reward, Dr S.H. mentioned that this could be comprehended by children. He also suggested making the traffic constraints more social, and displaying errors in a social way rather than by means of text.
- 7) The opinion of Dr S.H. about sidebar icons was positive. He mentioned that as soon as they are not moving and are not actively animated, they must not grab too much attention. When asked his opinion concerning the intuitiveness of visual icons, he suggested that another decision would be to not display the icons until they are reached, i.e. to display only those icons that have to be reached at a particular step. However, he also mentioned that the idea of displaying all the icons in black-and-white may be useful in case the user forgot the name of the location, and needs to look at the sidebar as a reminder. The expert also highlighted one potential problem of using abstract icons for locations: they might not provide enough information, because the guitar, for instance, does not look like a music shop, which is a grey building with a brown roof. Therefore, while it might be helpful in order to define the type of the location, it is not likely to be helpful if the child forgets how the building looks like, and it might be more useful to use real pictures of locations. He mentioned that one of the usual solutions in computer games is to use different guiding signs on the buildings themselves, such as arrows. However, he has mentioned another side to this approach: the guidelines and instructions that are displayed beforehand, look more realistic and are closer to the real-world task, and therefore, it might be helpful for both training the memorization of the location and the ability to find it without any additional cues.

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- 8) When asked about the default navigation keys, the expert mentioned that it might be hard for even older participants to press two keys at once. He also provided evidence from his studies that during the typing tasks, a usual challenge for children with ASC is to fulfil the tasks when the user is required to type a question mark (?), because it requires pressing two keys at the same time. Therefore, in the design of such games it is better to use one key per instruction. Moreover, the expert felt that the rotation angle might be too large, and that this might result in a disorienting effect. Therefore, the user might have better comprehension of the space if the rotation were slower.
 - 9) Concerning the idea of introducing the main character, Dr S.H. stated that the presence of a character is most probably an advantage of the game, because it increases understanding of the environment, helps the users to imagine themselves in the place of the main character, and makes the target more explicit, making it easier to understand.
 - 10) When asked his opinion about the 2D mode, and whether it might be stressful for children to navigate in 2D mode, when they don't have any particular idea of what to expect from the next step, he stated that, from his point of view, the 3D mode looks like the most appropriate choice when the task is related to navigation.
 - 11) Concerning the task of "asking for directions", Dr S.H. felt, that this task might be educative, and it makes the game more interesting.

4.6 DESIGN OF THE THIRD PROTOTYPE

During the design of the third prototype, all potential problems, as mentioned by the second expert, were analysed, and appropriate changes in the design were made.

4.6.1 DESIGN OF THE GAME ELEMENT

4.6.1.1 Navigation keys

During prototype evaluation, Dr S.H. provided valuable empirical evidence about difficulties that children with ASC may have in the tasks which require them to press two keys at the same time. This problem was not considered during the design process, because no literature support was found. Therefore, after the prototype testing, it was important to make appropriate changes, so that children only had to press one key per action.

4.6.1.1.1. HCI

- **Familiarity**

The arrow keys that were used for left, right, backward and forward navigation were not changed, because their functionality is very intuitive. These keys are used in many computational games, and this may increase familiarity with the system. However, the combination of keys “*Shift+left arrow*” and “*Shift-right arrow*” were substituted with single keys in order to avoid potential difficulties. The keys that were chosen for substitution, are located very close to arrow keys, because according to the research by Chen et al (1993), children with ASC may experience difficulties in finding the keyboard keys. Moreover, in order to keep the logic of “left” and “right” turn, the *Alt* key was assigned to the *turn left* action, and the *Ctrl* key was assigned to the *turn right* action.

4.6.1.2 Abstract icons

One of the main points made by the expert was that the use of abstract icons may not be helpful in finding a building, and may seem confusing. At the same time, the purpose of introducing abstract icons rather than real pictures of buildings, suggested by the first expert was the fact that these objects are able to provide information about the type of location. For example, the city bank looks like an ordinary skyscraper, and if the coins and money were not associated with it visually, a user could forget about the type of building he is looking for. The problem of remembering the visual representation of the bank building was resolved by means of introducing a picture of the city bank during the task. However, the point made by Dr S.H. is also reasonable, because a user may forget what the bank building looks like, and in that case the icons will look very confusing, moreover.

4.6.1.2.1. HCI

- **Predictability**

In case the user forgets the actual look of the building which is presented only once, there exists a probability that he will fully associate it with abstract icons, and wait for the analogous building to appear on the screen. The probability of such a result increases when considering the stereotypical thinking and weak imaginative skills of children with ASC. This can affect the predictability aspect, because the user will predict absolutely different visual location. For example, as Dr S.H. mentioned during evaluation, when the user is told that he will see a man on the other side of the road, and the icon of a man in a blue jacket is presented, a child could simply look for a man in a blue jacket, and ignore the actual character.

In order to resolve this problem, analogous icons were located near each target building (Figure 40). In addition, the title, representing the name of the location was placed near each icon. This approach supported the idea of associating each building with a particular icon and making the game engaging, and at the same time, reduced confusion over the actual buildings.

4.6.1.2.2. Believability

- **Agency**

The initial purpose of VENECA was the development of the game that would be very close to the real-world environment. In the real-world tasks, children would not have such explicitly presented cues in the form of icons on the buildings, so, this design decision may be considered by some research experts to be very “idealized” and not close to the real-world task. In the real world, children are most likely to receive the description of a location from their parents or friends, and this will be the only information available to them during navigation. Therefore, such simplification may lead to a reduced believability. It was also mentioned by Dr S.H. that while, it is easy to forget the icons, it may be a case, when the developer has made this design decision in order to make children memorize this information, and in that case, additional cues will contradict with initial purpose. Therefore, the decision to implement two versions of the game, with and without visual cues on the buildings, was taken. This will allow future experts to increase the difficulty of the task. This approach required implementation of an additional flexible feature on the control panel.

4.6.1.3 Turning speed

The next possible problem, mentioned by the expert was the fact that the turning speed is too fast, and this can result in a disorienting effect. The initial design decision was supported by the fact that users may have difficulties in rotating the character directly in front of the road, therefore, initial rotating speed was set at 90 degrees. However, as mentioned by the expert, really occurs in case of such a large rotation angle is selected. For children with ASC who experience difficulties in “orienting in unfamiliar space”, this design might create challenges, Moreover, the aspect mentioned by the expert refers to the system’s believability and flexibility of navigation.

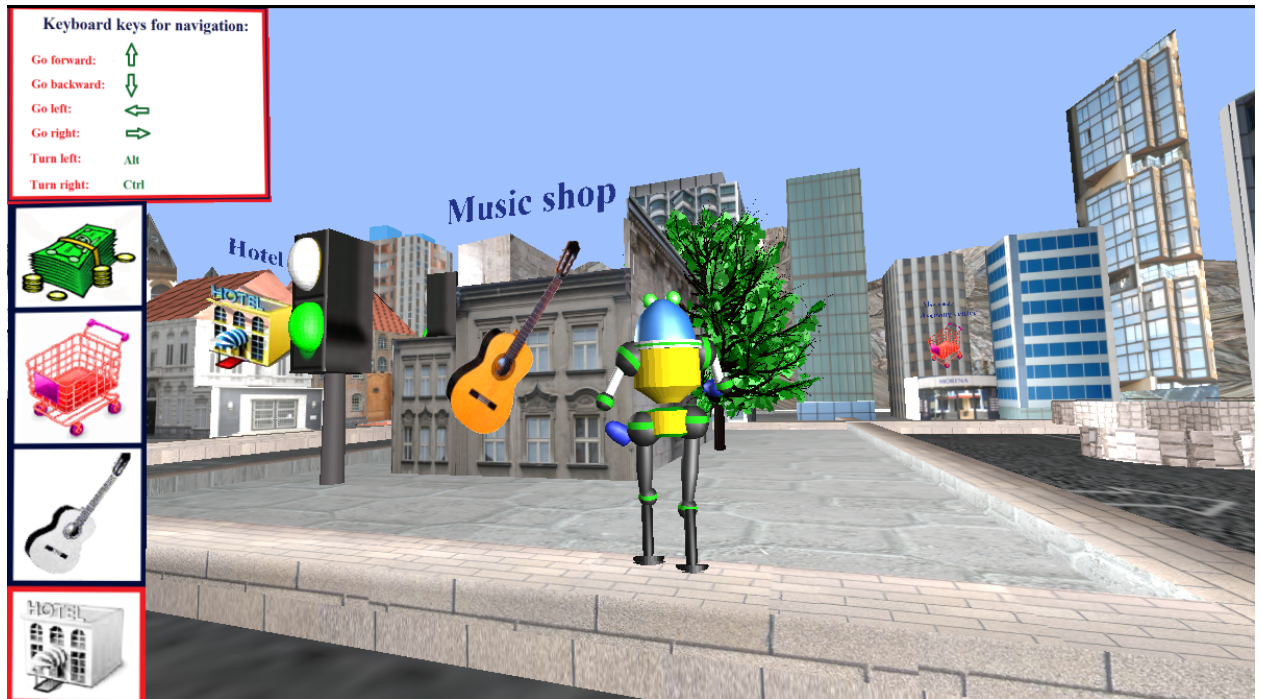


Figure 40. Visual cues with text, included near the buildings in order to simplify the task

4.6.1.3.1. Believability

Agency

During the real-world navigation, people usually require more than one step in order to turn 90 degrees. It may therefore be reasonable from this point of view, to reduce the rotating speed. The optimal and closest to the real-world task number of steps is three, therefore, the initial turning angle was reduced three times.

4.6.1.3.2. HCI

- **Flexibility**

The smaller rotation angle makes the navigation task more flexible and can be better controlled by the user. There may be cases when the user wants to rotate the character slightly in order to see the road, and the building on the side at the same time. With a smaller rotation angle he will be able to experience this effect, and slow down the changes of scene.

4.6.1.4 Social traffic constraints

While the suggestion to introduce social warnings, made by the expert, refers to an add-on, and is not related to the problems with the current design, it is able to provide an interesting less formal and more social way of displaying warnings. Both text messages

and social warnings have particular advantages, and can be used by experts depending on the initial purpose of the study. While text messages are very educative and give detailed explanation of traffic rules, social warnings have another advantage: they are easier to comprehend and are more engaging. This feature was therefore implemented, as an additional flexible variable for experts. Now, there are three possible ways of adjusting traffic constraints: displaying text warnings, displaying social warnings and turning the traffic constraints off. However, the term “social warnings” can cover a large number of different design decisions, including verbal warnings, gesturing, gazing, etc. Therefore, more detailed design decisions needed to be made.

4.6.1.4.1. HCI

- **Synthesizability**

The design of the text warnings is highly synthesizable because, the user clearly sees the change of the system’s state as a reaction to his incorrect action. During the social task, it was important to provide not only verbal, but also explicit visual change of state that could at the same time be social. As long as the user helps Andy in his navigation, it would be engaging for a child to see a warning message from his co-operator. Moreover, that would look very comprehensive. This was done by means of rotating the walking Andy to the camera, moving him slightly backwards, and displaying the warning. Another important feature about this warning is that during the warning process, the user navigation keys are turned off, it means that the user cannot disregard the rule, and continue crossing the road, as in case with error messages. In order to make this warning look believable, an additional “warning” animation of Andy was required, as well as a verbal warning. These decisions are presented below.

4.6.1.4.2. Believability

- **Gesturing and body movements**

As mentioned previously, the main difference between social warnings and non-social ones is that the former are less educative, but more comprehensive, because the user receives them from the main character. In order to make these warnings even more comprehensive, additional animations of Andy are required. When Andy obeys the traffic constraints, he stops his ordinary walking animation, turns to the user, points at the traffic light (uses joint attention), turns his head from side to side as a sign of disagreement with the user’s actions

and looks at the traffic light (gazing). During this animation (Figure 41), he also produces a short verbal warning. After this, Andy rotates back, and continues his walking animation. Such a kind of the warning can help the user to comprehend and observe the reasons of this warning: the inappropriate light shown by the traffic light.

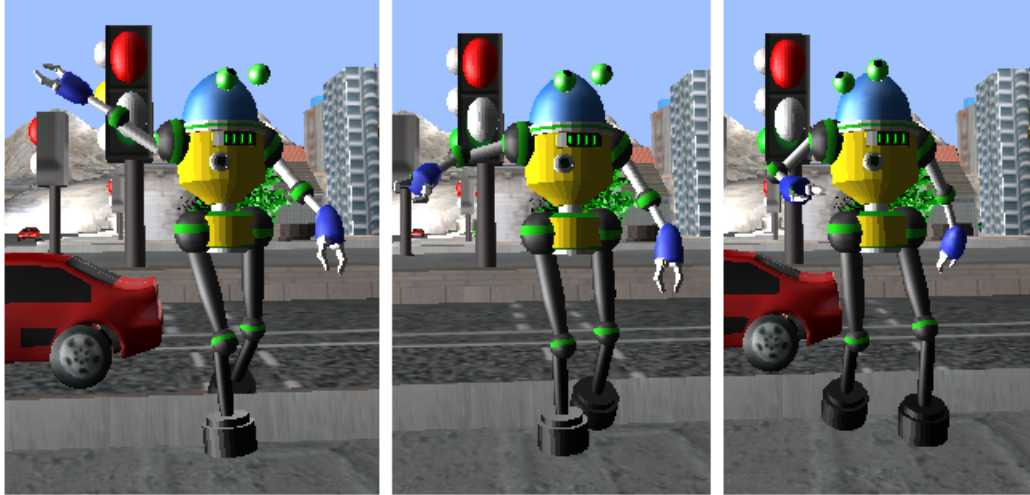


Figure 41. Andy displays social warning: rotates to the user, points to the red traffic light and rotated his head from side to side.

- **Speech**

As in the previous dialogs, of Andy, a robotistic voice was used for the social warning. The context of the warning is very short, because the social warnings are more observatory than educative. When pointing at the traffic light, Andy says: *“The traffic light is not green”*. Then, when looking at the user and turning his head from side to side, he says: *“I cannot cross the road”*.

4.6.1.5 The least level of believability

During the design of the third prototype, the remaining mode of the system’s believability was implemented by means of making the rendered pictures look more colourful and cartoon-like. All the shadows were also removed from the pictures. Some details of the buildings that refer to the believable textures were removed in order to make the scene look simpler (Figure 42). All other design decisions that refer to the realistic 2D mode were also inherited in the cartoon 2D mode.

4.6.2 DESIGN OF THE EXPERTS’ PANEL

Some of the modifications made in the experts’ panel have been already mentioned in the previous discussion, because they refer to additional game features included: the social

type of rewards and additional feature allowing to display or hide visual cues on the buildings.

However, there exist some additional aspects about the control panel that were discovered during evaluation of the experts' mode. Dr S.H. had a good understanding of the interface elements and their purpose, and the overall rules concerning the selection process. However, he could not specify the exclusive features: walking speed and traffic constraints. He has also mentioned that he would expect to see the dynamic traffic in the 2D mode. Even taking into account that notification messages are displayed when the user selects 2D modes, it would be a better decision to make the game more predictive.



Figure 42. Cartoon mode of the game


4.6.2.1. HCI

- **Learnability**

Predictability

The user is notified that the walking speed and traffic constraints are changed only after he has selected the 2D mode. It would be a better decision to make these notifications more predictable, and for both walking speed and traffic constraints to mention that they are available only for the 3D mode. This approach was used in the modified version of the control panel (Figure 43).

Welcome to VENECA (Virtual Environment for Navigational Education of Children with ASC)



Please, specify the options for all the game features:

Instructions:

Delivered in a verbal form: ☐

Delivered in a written form: ☐

Traffic constraints during road crossing:
(for 3D mode only)

Display warning messages: ☐

Display social warnings: ☐

Don't display traffic constraints: ☐

Type of rewards for the completed steps :

Social: ☐

Non- social: ☐

Character's walking speed
For 3D mode only

Slow: ☐

Medium: ☐

Fast: ☐

The level of the environment's believability:

Realistic 3D mode (highest level): ☐

Realistic 2D mode (medium level): ☐

Cartoon-looking 2D mode (lowest level): ☐

Visual cues on the buildings:

Display: ☐

Hide: ☐

START

Figure 43. Modified control panel

4.7 EVALUATION OF THE THIRD PROTOTYPE

4.7.1 METHOD

4.7.1.1. Participants

Dr G.R. was invited as a research expert for the third prototype evaluation. This expert has a strong background in psychology. The research interests of Dr G.R. lay in various behavioural aspects of individuals with ASD:

- Syntactic alignment in children with ASD;
- Dyspraxia observed in children with ASC;
- Deficit in producing intransitive gestures;
- Organisation of the working memory in children with ASD;
- Imitation of meaningless gestures;

-
- The ability to perform multitasking actions in adults with ASC.

Dr G.R. has taken part in a number of research studies with children with ASD. Moreover, some of these are oriented towards using educational VEs. One of these research studies (Rajendran, 2011) has a relation to some of VENECA's principles. This study was already described in Chapter 2 (recall VET system). The study concerned the exploration of multitasking skills in high-functioning adults with ASC. VENECA, as already mentioned, also uses the multitasking approach, but, the complexity and number of multiple tasks can flexibly be controlled. Another similarity between VET, the software used in Rajendran et al's (2011) study and VENECA is that the main task is based on navigation. However, in VET the main actions take place in a school building with three levels, while VENECA specializes in street navigation.

4.7.1.2 Materials

During the third prototype evaluation, all the modes of VENECA were implemented. Additionally, some changes were included in response to the second prototype evaluation:

- 1) A flexible feature was added allowing the inclusion or exclusion of visual cues on buildings;
- 2) An additional social type of traffic constraints was added;
- 3) Navigation keys were changes to use only one key per action;
- 4) The rotating angle was reduced.

As during the previous prototype evaluations, the following technical specifications were used:

The demonstrated game was running not from the developing environment, but from an executable file because this is supposed to be the running mode used by future experts. The running speed of the game was 30fps. The demo was presented on an HP 4720s ProBook laptop with screen size of 17.3 inches. The game was running in a full screen mode with the highest level of brightness and volume.

The audio recording capability of the Apple Ipod 4 was used to keep log of the expert's advices, and analyse all of them after the evaluation.

A set of semi-structured interview questions was used in the third evaluation, as during the second prototype evaluation. The same ranked list of questions was used, but some of the questions asked during the first prototype testing were not included, due to time limitations.

4.7.1.3 Procedure

As during the second prototype testing, the overall duration of the third evaluation was 40 minutes.

As during the first prototype evaluation, official permission for making an audio recording of the whole evaluation process and subsequent usage of this information as a part of the Master's thesis was requested from the expert. After Dr G.R gave his permission, the evaluation process started.

During the first step of the discussion, Dr G.R. provided information about his experience in relevant fields, and provided more information about the navigation task using VET system. This information was summed up in section 4.7.1.1.

The next step was the introduction of the system by the developer. There was a slight difference from the introduction used during the second prototype evaluation, because during analysis, it was discovered that when talking about the target user group, it was useful to mention the skills that users from the target group are expected to have. The modified introduction is presented below:

“The given software is a research tool with a game as a cognitive element. The game is developed as a Virtual Environment which represents a part of the city. The main task is based on navigational education, but there are some other educational goals that will be discussed later. The target user group are children with ASC between 9-14 years old. At that age, children with ASC are usually supposed to have required reading skills. Even though, these skills may vary depending on the impairment, they are usually sufficient in order to comprehend the written information. Moreover, at that age, children with ASC are usually familiar with computer technology, and have particular skills in using a keyboard and computer mouse. In order to simplify their usage of keyboard, each navigation action is assigned to a single key. This tool provides research experts with the possibility of flexible selection of different desirable features. This is the control panel which was designed specifically for this purpose”

Before launching the game, Dr G.R., as a researcher with a particular experience in multitasking navigational environments, started a short discussion about the purpose of and the motivation for creating a game, focusing on this aspect, while children with ASC usually have very strong visual processing skills, and some experts may argue the necessity of such a kind of software for children with ASC. In response, the demonstrator mentioned the potential difficulties with attention that can occur during multitasking, the problems with orienting in unfamiliar environments and stress that children can experience during such tasks. Dr G.R. agreed, saying that he observed a particular difficulty that children experience in multitasking games in terms of dividing and organizing their time between different activities. He also mentioned, that the aim of the developer to concentrate on a task which required performance of different actions at the same time and dividing attention between different tasks, were motivated by a good logic, and may result in an interesting future research.

After this discussion step, the demo of the game was launched. Considering that Dr G.R. is an expert with a stronger cognitive background, it was decided to concentrate more on the studies that he could launch as a researcher with the control panel rather than on the usability problems. Therefore, unlike during the experiment with Dr S.H., the number of usability questions was reduced, but for the possible studies, the expert was asked to specify all possible ones:

- 1) Given the name of the software, could you guess its main purpose without any introductory information?

Given a set of game features could you specify for each of them:

- How do you understand the purpose of this feature?
- What study you could make using this flexible feature?
- What is an importance of such study for users from the target group?

After these questions have been answered, the system was adjusted to the following features:

- Both verbally and non-verbally delivered tasks were specified;
- The most realistic 3D mode was selected;
- The type of rewards was adjusted to social;
- The text-based traffic constraints were turned on;
- The speed was set to the medium level;

-
- The visual cues on the building were turned on.

The main difference of the settings from the previous prototype testing were the existence of visual icons on the buildings and the inclusion of traffic constraints.

When the selection process was finished the mode with the selected game features was launched. The process of the game demonstration was not interrupted by any questions, and only sometimes different design decisions were highlighted by the demonstrator. After the process was finished, the expert was asked several questions:

- 1) What advantages of making the messages manageable by children (users) by means of clicking the OK button when compared to the automatic proceeding to the next step can you mention? Might there be any benefits of the opposite approach? Might that affect the level of the system's unpredictability and cause the same stress as in real-world tasks? Might this decrease a feeling of control of the system?
- 2) Currently, the verbal representation of the navigation keys is displayed only once, at the beginning of the game. It was suggested during the first non-formative prototype evaluation. Please, specify the benefits or shortcomings of this approach for the target user group. What is a probability that the opposite approach (displaying reminders at the beginning of each task) will be annoying for children?
- 3) What is your opinion about the idea to introduce the icons, such as doorbell, question, and tickets only when the child reaches the location? (Error-prevention question) In case, they would be visible all the time, what is a probability of that frequent messages with errors will disappoint the user of the target user group? What do you think could be an advantage of another design? Do you think, in case the system could count errors, you could use this data for comparison of modes?
- 4) What do you think about the idea of introducing the real-world task not in the context of "you have to do this", but in the context of the scenario, with game story and purpose? Do you think that might motivate children? What disadvantages of this approach can you mention?
- 5) Could the idea of introducing an additional option for social warnings be useful?
- 6) What can you specify about the amount of text on the screen?

In addition, unlike during the second prototype evaluation, Dr G.R. was asked to evaluate the system's features on scale of 0-4, according to 10 usability heuristics introduced by

Nielsen (Dix et al, 2004, pp 324-327). For this purpose, two different tables were designed for the experts' mode and the game element.

4.7.2 RESULTS

4.7.2.1 The control panel

Before giving answers about the control panel, the expert mentioned that one of the features that he, as an expert would find very useful, is the implementation of some logging mechanism that would record all the actions performed by the user, so that they could be analysed in the future. As an example, he has mentioned the VET system, which uses a logging mechanism.

1) When asked about the completeness of the information provided, the expert mentioned that he would probably need more information about the game. While the name provides a general idea about the game, and he can understand the actions from the options very roughly, more information would be useful. That information does not necessarily need to be included into the game; it could be presented as documentation or in a printed format.

2) When asked to specify the studies for each game feature and their importance, Dr. G.R. mentioned the following research questions.

For the verbal and non-verbal presentation of the task, the expert mentioned that it could be used to compare of users' verbal versus non-verbal comprehension. It would be very useful to have such a kind of modality, because while children are no able to say much, they may have a better understanding of instructions.

For the character's walking speed, an expert has mentioned potential usability problem in making the speed "fast", "quick" and "medium". While this is subjectively decided by the developer and there is no any additional descriptive information, expert may be not able to make an appropriate decision. He mentioned that it might be useful to create a scale or provide concrete qualitative parameters. This approach would suggest a more flexible design and make the system more useful.

For the traffic error messages, the expert mentioned that the description could be more specific, because "social" may refer to verbal warnings, emotions, and gestures. This must

therefore include more specific description of exactly what kind of social warning will be displayed.

For different levels of believability, the expert mentioned that this feature could lead to interesting research related to the ecological validity of the system. It is definitely interesting to analyse whether the more believable environment would encourage children to explore it, or if a less believable environment would be more comprehensive. Dr G.R. also mentioned the subjectivity of believability, and that it is possible to make an environment very believable, but not functional enough for the target group because the details included are not actually needed. Believability can also directly affect generalization (the aspect of intentional simplification, presented at the beginning of this chapter). The expert has also mentioned previously discussed theory by Plaisted (2001) about reduced generalization, which suggests that children with autism are weak at generalizing, mainly because they are not able to understand what features are related to other environments.

4.7.2.2 The game element

There were some brief points that the expert made during the demo of the game:

- Using a storytelling style is a very good idea, and children will probably like that.
- The fact that the task is delivered both verbally and non-verbally looks very useful for comprehension.
- The idea of using the icons is very useful.
- The learning process of the game, as he understands it, is incidental: there is no explicit evidence that children are learning anything, this process is “hidden” inside the story. This is the sort of information that the researchers would like to know before they launch the game.
- It might be useful to show a sort of a map during navigation, as used in VET.
- The robotistic voice sounds very engaging.

Dr G.R. provided the following answers to the specific questions asked:

- 1) When asked about the idea of making the messages fully controllable by children, he supposed that since children have to memorize this information, this decision is very useful for them in case they have to re-read it;

- 2) When asked about the verbally presented navigation keys, the expert assumed that the idea of presenting traffic rules at the beginning of every task will be a lot for children, and the current design looks more appropriate.
- 3) Dr G.R. mentioned that the approach of making the game less error-initiative by presenting the objects only when the character reached a location is a good one. When asked whether the number of wrong clicks would potentially be useful for researchers, he mentioned that it is a difficult question because while it might be useful, there is always a probability that children might just click on the icon all the time, and get frustrated because of the fact that there is no response.
- 4) When asked about the idea of putting the story in a context of a social story, the expert mentioned the work by Rutten et al (2003) already discussed in this thesis, and stated that this is a good idea for motivating children.
- 5) When asked about the idea of introducing social warnings, the expert specified that pointing may be a good educational cue, and children will most likely be engaged by the warnings coming from the main character.
- 6) When asked about amount of text on the screen, the expert assumed that it will be understood by children; but that it would also be useful to introduce an option that would allow them to retrieve a task in case they forgot it.

4.7.2.3 EVALUATION OF THE GAME BY MEANS OF USABILITY HEURISTICS

Presented below are two tables, one for the control panel and one for the game element, that display the expert's evaluation of the software in terms of Nielsen's usability heuristics.

Control panel

Heuristic	Scale
Visibility of the system's status: is the user always informed of what is going on?	0
Match between the system and the real world	0
User control and freedom: how easily is the user able to recover from errors?	1

Consistency and standards:	0
Error prevention: how helpful is the system in preventing the user from making errors?	2
Recognition rather than recall: Does the user need to remember the information from another part of the dialog when he proceeds to another stage of the system?	0
Flexibility and efficiency of use: Does the system suggest flexibility in adjusting the game to specific needs of the user?	0
Aesthetic and minimalistic design: Does the system include elements that can interrupt the simplicity and ease of use?	0
Help for users to recognize, diagnose and recover from errors	0
Help and documentation: Is there a need to introduce additional documentation into the system?	2

Table 2. Results of heuristic evaluation for the experts' usability

Game mode

Heuristic	Scale
Visibility of the system's status: is user always informed of what is going on?	0
Match between the system and the real world	0
User control and freedom: how easily is the user able to recover from errors?	0
Consistency and standards:	0

Error prevention: how helpful is the system in preventing the user from making errors?	0
Recognition rather than recall: Does the user need to remember the information from another part of the dialog when he proceeds to another stage of the system?	2
Flexibility and efficiency of use: Does the system suggest flexibility in adjusting the game to specific needs of the user?	1
Aesthetic and minimalistic design: Does the system include elements that can interrupt the simplicity and ease of use?	0
Help users recognize, diagnose and recover from errors	0
Help and documentation: Is there a need to introduce additional documentation into the system?	0

Table 3. Results of the heuristic evaluation for the game element

- 0-** I don't agree that this is a problem of the system;
- 1-** Cosmetic problem: need not be fixed until there is extra time available for the project;
- 2-** Minor problem: fixing must be given the low priority;
- 3-** Major problem: important to fix, should be given the high priority;
- 4-** Usability catastrophe: needed to be fixed before the software is released.

4.8 FOURTH AND THE LAST DESIGN ITERATION

At this stage, the results from the last prototype evaluation were analysed in the complex with some previous doubtful ideas, and the final changes in VENECA's design were made.

4.8.1 GAME ELEMENT

4.8.1.1 Retrieving the task

The overall impression of Dr G.R. about the game design was very positive. In terms of the usability criteria, there are two low priority problems that can be related to the flexibility and recognition problem. Returning to the demonstration of the game, it is easy to see that both of these features are related to the instructions' comprehension, which was the only improvement mentioned by the expert about the game mode. There exists a probability that a user from the target group can easily forget the task, and therefore, it would be useful to provide a way to retrieve it. Therefore, an additional icon in the right corner of the screen was included, so that the user could recall the current task in case he has forgot it (Figure 44). The icon dynamically detects the current task, sends the message to the task element and displays it in the current location of the camera. This allows recall of both verbal and text tasks, depending on the form of the task delivery specified by the expert. This feature would also be very useful according to different HCI criteria.

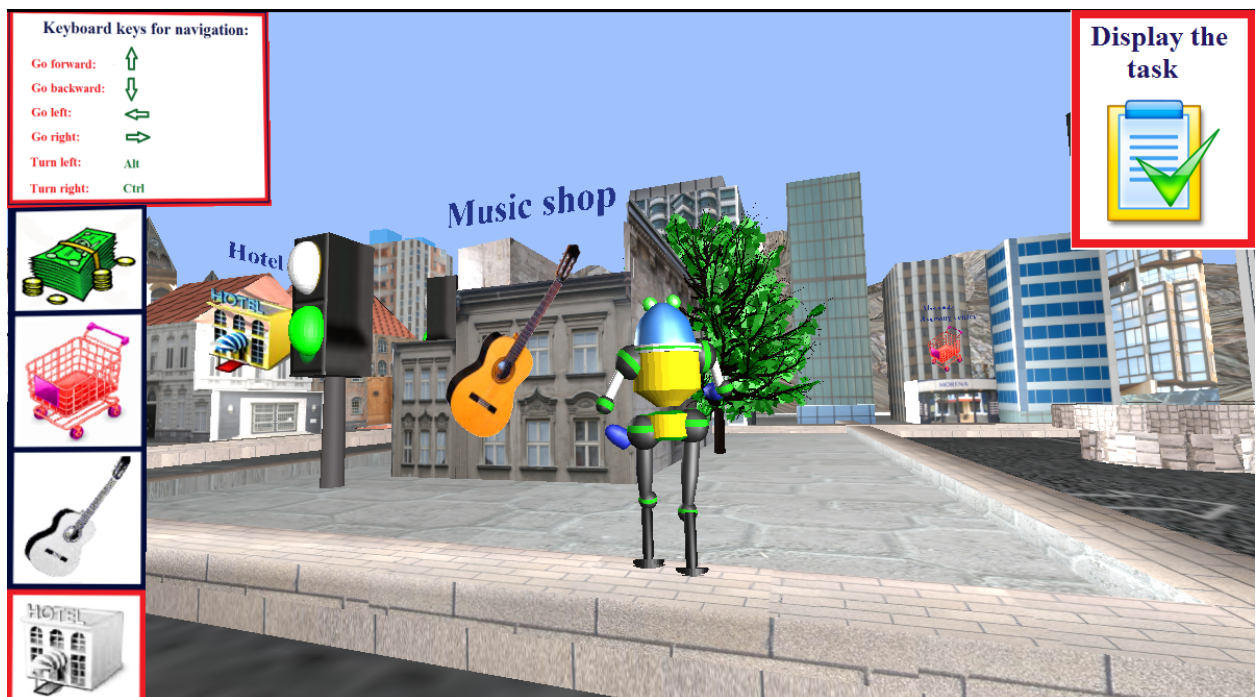


Figure 44. Additional “Recall task” options implemented

4.8.1.1.1. HCI

- Flexibility

Dialog initiative

Initially, it was mentioned that the logic of the game assumes that the system is fully “system pre-emptive”, i.e. all dialogs are initiated by the system, and the user can only respond to them by means of fulfilling the task. However, the introduction of an additional button that would allow such initiation from the user’s side could create a feeling of “*user pre-emptiveness*”, and make the user-system interaction less one-sided.

- **Robustness**

- Recoverability**

Recoverability refers to the degree of transition between different states, therefore, the potential to recall tasks would provide an illusion of the system’s recoverability. The “error” in this case would refer to the fact that the user forgot the task, and the recoverability partially allows the user to return to the state when the task was presented. However, it must be highlighted, that the recoverability is “partial”, because only the window with the task is recovered, but the location of the character in the environment stays the same.

4.8.1.2 Inclusion of the map

As the expert taking part in the first evaluation, Dr S.F-W mentioned that, in the future it would be useful to see the map during navigation. This suggestion was already analysed during the design of the second prototype, and at that point it was decided that more expert opinion was needed, due to potential technical challenges related to the graphical complexity of the game. Additionally, such a map could be very interruptive, considering the number of interface elements, such as navigation rules and graphical icons. Introduction of the map could overpower the FOV, which must grab the main attention. Dr G.R. also mentioned the complexity of the scene that could be achieved in case the map was presented on screen. He has therefore suggested developing a static map that can be printed and provided for an educative purpose. At this moment, this decision was considered as the most optimal one, therefore, the rendered map was developed and included into the documentation. Possible solutions of how to make the map “real time” were analysed (see Chapter 6).

4.8.2 CONTROL PANEL

4.8.2.1 Subjectivity of the game features

A useful point made by Dr G.R. refers to the fact that the “navigation speed” game features seem subjective. This is a very important feature that might decrease the usability of the game in terms of the user’s control and freedom (rated as 1 during the heuristic evaluation).

4.8.2.1.1. HCI

- **Learnability**

Predictability

While the “medium” speed is considered “medium” by the developer, according to the experts’ points of view, it might be “slow” or “quick”. The fact that they don’t know the exact qualitative value of the speed, makes the environment unpredictable for experts. Therefore, the descriptions “slow”, “medium” and “fast” were substituted by the actual parameters measured in “frames per second”: 0.005 fps for the slowest speed, 0.02 fps for the medium one and 0.04 fps for the fastest one (Figure 45).

4.8.2.2 Lack of additional information (for “social” behaviour and “believability” levels)

As mentioned by Dr G.R., “social rewards” may refer to a wide range of actions, and a more precise specification is needed, because experts would like to know in advance what to expect from the system. This again refers to the system’s predictability. Moreover, a precise specification of actions included in the social task will prevent potential errors by the experts (rated as 2 during the heuristic evaluation). Therefore, it is crucial to change the descriptions of the social behaviour for both rewards and warnings into more descriptive ones.

During the discussion about the system’s believability, Dr G.R. also stated that the term “believability” is very subjective, and it would be a better decision to specify the concrete features changed in less believable modes.

Character's walking speed	
For 3D mode only	
0.005 fps	○
0.02 fps	○
0.04 fps	○

Figure 45. More objective description of the navigation speed

4.8.2.2.1. HCI

- **Learnability**

Predictability

In order to specify concrete actions referring to the social behaviour, and to avoid putting too much text on the screen, additional text information was assigned to each type of reward and warning. This text was displayed when the cursor was placed over the option (Figure 46).

For social rewards, it was specified that an active character, using gesturing, pointing, verbal speech and emotions, appears on screen. For non-social rewards, it was specified that the visual icons light up, and create the “collecting effect” on the left sidebar.

For social warnings, it was specified that the main character explains the error by means of gesturing, pointing and verbal speech. For non-social warnings, it was specified that a message with plain text and pictures, explaining traffic rules in an educational way appears.

In order to make the believability levels more predictable, the precise specification of factors that make the game more believable was given: dynamic objects, believable textures, and 3D scene (Figure 46).

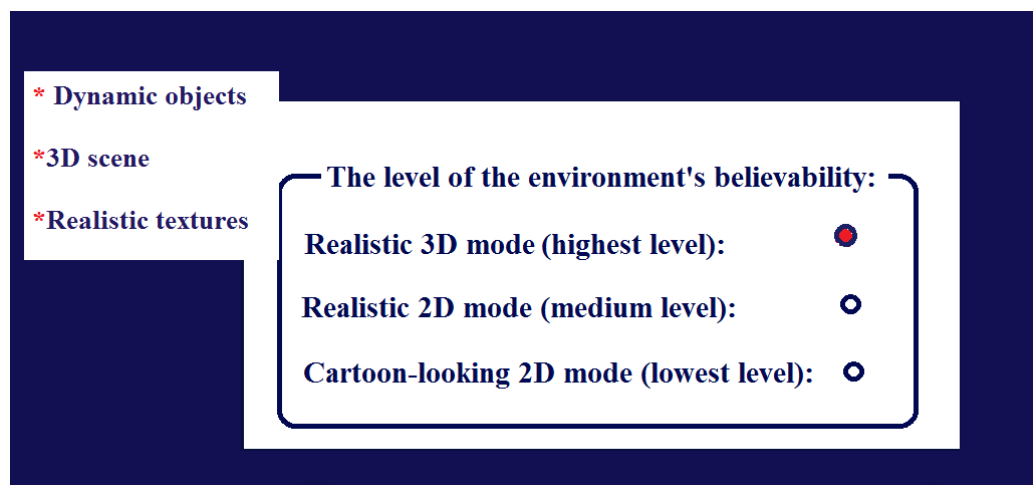


Figure 46. Additional descriptive information appearing when the cursor is placed over the option

4.8.2.3 Hidden educative aspect and initial introduction

Dr G.R. had a good understanding that the game was organized in a way in which the user is learning different skills, but this learning is hidden in the story of the game. Dr G.R. mentioned that this information needs to be delivered to the experts before setting the

game. This feedback may refer to the documentation, the feature rated as 2 during the heuristic evaluation. Moreover, in order to increase the predictability of the game, the additional information during introduction of the game could also be included information must be included into the documentation.

4.8.2.3.1. HCI

- **Learnability**

Predictability

In order to provide more information about the game strategy and not to put too much text into the control panel, the control panel was added with a text which states: “for full description of the software, please, refer to the documentation”). The documentation with the detailed description of VENECA was generated at the last stage of development, and the information included into this document will be presented in Chapter 5.

4.8.2.4 Logging the actions

Another important feature mentioned by Dr G.R. at the beginning of evaluation was that he would expect the system to keep log of all the user’s actions. This feature would be very helpful in for research experts. A possible way of doing this is to install a video capturing software, which could run at the same time as the game and record the screen actions. At this point of the design process, in order to avoid situations where a researcher forgets to run the software, an open-source screen capturing software was integrated into VENECA. It is automatically called when the game launches. It was tested along with the running game, and was able to record all the actions happening on the screen. Possible alternative approaches for logging the actions will be described in Chapter 6.

CHAPTER 5. IMPLEMENTATION AND DEPLOYMENT

Returning to the waterfall model introduced in Chapter 3, the final process of the software implementation, following the iterative design and prototype testing, is the implementation of the final version of the software and documentation. This chapter presents the final set of features included in VENECA's version as a research tool. Moreover, it provides information about the process of developing documentation. The information included in the final documentation, was suggested by the information about the intuitiveness of the control panel and experts' understanding of the game features.

5.1 OVERVIEW OF THE FINAL GAME FEATURES

The final version of VENECA included the following set of features:

The control panel: This provided the possibility of selecting the navigation speed, and choosing between three types of traffic constraints, social or non-social rewards, verbally or non-verbally delivered instructions, inclusion or exclusion of visual icons, and three levels of the system's believability.

Believability levels: The main difference between the highest and the middle level of the system's believability was that the navigation task in the more believable mode was more agent and simulated the feeling of navigation in 3D mode. The traffic was implemented in a dynamic way, with the moving cars and changing traffic lights. In addition, the characters that were used in the 3D mode were more believable, because they were dynamic rather than static, and could display supporting gestures, emotions and actions. The main difference between the middle and the lowest level of the system's believability was the presentation of locations in terms of a less believable and brighter colour palette, and the absence of the shadows and different details of the scene.

Navigation speed: The main difference between the navigation speeds is the number of frames per second that are passed by Andy per step: 0.005, 0.02 or 0.04 fps.

Visual cues: The main difference between inclusion and exclusion of visual cues is the abstract icons and the names of the locations that are displayed (when turned on) or not displayed (when turned off) on the tops of the target locations.

Format of the tasks: The verbally and visually delivered tasks refer to their delivery format: the tasks can be presented either as verbal instructions or as written text with pictures. The game logic allows selection of both options at the same time.

Rewards: The main difference between the two types of rewards is that for the non-social reward the visual icons appear on the sidebar, as if the character were navigating through the environment and collecting them. For the social rewards, each location includes the same icons. However, for the new task, the icons disappear and the feeling of “collecting” decreases. In addition to the icons, in the social mode, the character gets a visual object associated with a location (not representing the location), and presses it in order to get a reward. A reward is delivered in the form of a game character that is assigned speech, gestures and emotions, and which explicitly says to the user that the task is completed.

Traffic constraints: The main difference between the three types of traffic constraints is that for the non-social type of constraints, when the user obeys the rules he receives an educative text message with integrated pictures, explaining the road crossing rules. When the verbally delivered tasks are selected, this text will also be spoken. If the written presentation of tasks is not selected, the user will only hear the road crossing rules. For the social traffic constraints, the main character, the robot Andy, rotates to the user, points to the traffic light and looks at it, explains that the light is not green and therefore he cannot cross the road, and then rotates back, and continues walking. The user can continue navigation only when Andy has completed his warning action. When the traffic constraints are turned off, the user can cross the road even if the traffic rules are obeyed, and no stopping force or error messages will appear. It is important to highlight that this option does not turn off the traffic, because this would affect the believability: the cars and traffic lights still continue to be dynamic, and only the constraints change.

It is important to highlight that all the possible combinations of the features in VENECA are allowed unless the opposite is specified explicitly (recall that the 2D mode is incompatible with traffic constraints and navigation speed). For example, the 2D mode might have a non-social reward, a verbally delivered task and inclusion of visual cues on the buildings, and each of these features could be changed.

5.2 DESIGN OF VENECA'S DOCUMENTATION

A complete version of the software must provide the user with a sufficient amount of information to help to adjust to the system. The deploy step of the waterfall model also includes the design of the required documentation.

When discussing task analysis in Chapter 3, it was mentioned, that one of the reasons that this step is very important, is that all the steps, clarified at this stage, can subsequently be used for the construction of user manuals. Documentation for VENECA also included such a manual. It is distributed in a “.pdf” format in a document called “*Instructions guide for experts*” and contains the following types of information:

- 1) The task analysis of the experts' actions was modified to include the features added during the design process, and was then added into the manual, helping to set up the system step by step.
- 2) A detailed description of all the game features, their meanings and dependencies between them.
- 3) A detailed description of the user's expected actions, specified step by step for every mode and combination of modes separately.
- 4) A section called “*Recommendations for setting the research study*”, which provides other information also mentioned during the task analysis, related to the recommended keyboard stickers and the specific keyboard and mouse types that could help child users to complete the task. It also contains some hardware recommendations, such as a hard disc space of at least 300 Mb and RAM of at least 2 Gb. Moreover, different suggestions of how the user's actions can be logged are provided. These include the implemented video capturing feature and additional possible options.

5.3 LICENCE

The common pack of VENECA includes the licence text document.

It provides general information about the version of the software (1.1), the author and the year of implementation. According to the licence policy, the following actions are allowed without the requirement of any specific permission:

- 1) Changing the final code;

-
- 2) Translating into other programming languages;
 - 3) Using in research experiments;
 - 4) Mentioning in publications for critical analysis, research reports or any other purposes;
 - 5) Distribution for personal use;
 - 6) Distribution for commercial use;
 - 7) Modification of the design decisions;
 - 8) Inclusion of Add-ins of different features;
 - 9) Implementation of new versions under the licence of a new author.

In all these, the initial set of features implemented for the first version must be attributed to the author.

CHAPTER 6

DISCUSSION

6.1 Are the goals achieved?

At the end of this project, a full set of goals, specified during the task analysis stage was achieved. VENECA was tested by changing different flexible features, and demonstrated reliable work in all combinations of modes. Despite the challenges with GUI elements, it became possible to simulate the control panel, and the feedback gained from the experts demonstrated that they don't feel any confusion understanding features of particular elements. In addition, the stages of prototype evaluation suggested additional flexible features not considered during task analysis: visual cues on locations. The ideas of using visual icons for locations, and of introducing the main robot character, suggested during the first prototype evaluation, were also supported and positively accepted by further experts.

VENECA allows investigation of all the questions, mentioned in the Introduction. Each of them has a high importance for future research (see Chapter 1). Moreover, the combination of features that was achieved, including the main navigation task provides a complete, optimal and interconnected set of elements that might be interesting for future researchers.

During this thesis, it was mentioned several times that the majority of flexible features can be combined with each other and lead to new studies. Considering the six features (two of which are not exclusive) with two or three options in each, it becomes clear that there are thousands of possible combinations. This suggests a very high degree of flexibility and makes VENECA a potentially very useful tool for a large variety of studies in the future.

VENECA avoids all possible stressful stimuli that can be met in Josman et al.'s (2008) system and in VET (2011). The road crossing task provides educative or social information, rather than trying to simulate an accident. The highest degree of VENECA's believability overcomes existing systems because of more believable textures in the scenes and because of the characters' personality. This suggests the high ecological validity of VENECA and less generalization requirements for future final users.

When comparing VENECA to the program that was used in the study by Rudden et al. (2003), one could argue that VENECA could inherit levels of difficulty as an additional flexible feature. However, by examining the set of flexible features, it is possible to notice

that VENECA allows variation of difficulty, but in an implicit way. This approach looks more objective for both the expert and child users' requirements, compared to pre-defined levels. For example, experts may turn off the visual cues on the higher levels of difficulty of their studies and present a more realistic 3D scene, while on the lower levels they can use cartoon scenes and visual cues. In order to simplify the task, researchers may also turn off the traffic constraints. Depending on the writing and verbal skills of their target users, particular types of instructions can simplify the usage of the system by children. Slow navigation speed can simplify navigation for children with motor limitations. All these examples suggest that VENECA supports different levels of difficulty, but the elements that define this difficulty are flexible in themselves and separated from each other, which allows experts to define the desirable level of difficulty more precisely.

When discussing error initiation, VENECA suggests the highest support in order to avoid errors. Except in the road crossing task (where warnings are displayed in an educative way), it is not possible for users to make errors in finding the location, because, the visual object for a reward appears only when a character comes near the location.

The idea of using Blender during task analysis, made it possible to achieve a high degree of platform independency for both exploitation and further development of VENECA.

6.2 FUTURE WORK

Even though, the first version of VENECA provides enough functional support for research users to investigate questions, as stated in the introduction, there exist many possible directions in which VENECA could be improved, extended and made even more flexible. In this section, the majority of interesting future extensions of the system are analysed, some alternative directions are compared and their importance is evaluated.

6.2.1 BELIEVABILITY LEVELS. TOWARDS HIGHER FLEXIBILITY

Even though the current version of the system includes three well-justified believability levels, these levels may not be enough to answer the initial question: "To what extent can the increased believability assist users without affecting their comprehension?". A larger number of intermediate levels may be required in order to discover the necessary "border", starting from which the system stops assisting users and decreases their comprehension. There are two possible directions in which the levels of believability can be made more flexible. One direction suggests implementation of additional variations of scenes. In this

discussion, this will be referred to as “towards variations” methodology. The second direction is based on switching the believability question from developers to experts, and will be referred to as “towards building” technique.

6.2.1.1. Towards variation of three main variables

When analysing the approach used in this project, it can be observed that different levels of believability were achieved by using combinations of different scene parameters: 3D and 2D space, dynamic and static objects and textures. The medium level of believability used a combination of static objects, a 2D environment and believable textures, while the lowest level included static objects, a 2D environment and less believable textures. Future developers can implement a larger number of such variations by means of fixing one of these three parameters and changing the remaining ones, which will suggest more possible scenes with different levels of believability between the highest and lowest level. For example, during the second evaluation, the expert expressed his expectations concerning the existence of dynamic objects in 2D mode. This observation can be successfully used in order to implement an additional medium level of believability, which would include a 2D scene and realistic textures, but static objects. The cars could be presented as moving 2D objects, and the traffic light could be simulated by means of changing the colours of flat images. The same dynamic scene could be implemented for the less believable cartoon mode. Another scene could be achieved by means of fixing the 3D scene and dynamic objects and changing the textures. This would suggest a new level, with 3D mode and cartoon-like objects. Following the same principle, the 3D scene with believable textures could be changed so that the objects become static.

6.2.1.2. Towards building

This direction may require much more time and effort than the previous one, because the main idea is to switch the responsibility of building an environment from the developer to the experts. This goal can be achieved by developing a fully flexible system with a collection of pre-defined modelled objects and textures. Given the current existing model of the city, it is possible to group different types of objects - such as trees, cars, etc. – together and make their visibility and texture settings manageable from the control panel. The experts could then build their own environment by selecting objects and assigning them necessary textures from a selection menu. For the game characters and other dynamic

objects, there could be collections of animations and sounds that experts could select during the environment building.

6.2.1.3. Which direction is optimal?

The latter approach may be very time-costly and require a lot of analysis in order to implement such high degree of flexibility. However, there are obvious potential benefits of this approach. One of the obvious questions for the “towards variations” approach is how to rank all the levels of believability if equally-important variables are changed. Currently, the system uses a logically correct approach when the middle level of believability uses two non-believable features (2D scene and static objects) and one believable feature (textures), and for the least believable mode, all three features are made non-believable. However, if the features are varied individually, such a ranking would be difficult. For example, which is more believable: a static 2D mode with believable textures or a dynamic 2D mode with cartoon features? At the same time, such a ranking is important for answering the question about believability extent. Additionally, the system currently uses three separate scenes for different modes, because the 2D and 3D scenes and the textures are absolutely different. The implementation of different variations of levels will increase the number of scenes and result in a large explosion of memory requirements. Another aspect that makes the “towards building” approach preferable is the fact that it is more objective, and allows experts to express their own understanding of what makes the environment believable. From the HCI point of view, such an approach would be very much preferable, because it provides very high degree of flexibility in two-sided communication between the expert users and the system.

6.2.2. PERSONALIZATION. TOWARDS HIGHER FLEXIBILITY

Even though, the first version of VENECA considers some individual requirements (navigation speed) and preferences (for social or non social rewards) of final target users, the degree of personalisation can be increased in the future versions. During the analysis of design decisions, it was highlighted that the current design of the game element suggests one-sided interaction between the system and children users, because the system initiates all the dialogues in the form of a task, and the user responds to these tasks by finding a required location. If the future versions could include different options for the user inside the game element rather than during the adjustment process, two results could be achieved: flexibility in terms of user-system communication, and a higher degree of personalisation.

Even though, the robotistic character Andy will most likely be appreciated by children users, as was analysed during the design process, future versions could include a collection of main characters and allow the final target users to select the character of their preference at the beginning of the game. Moreover, instead of following the pre-defined path and the game story, the system could allow the user to control the navigation at each step of navigation, and select the future destination from a number of possible points. For example, the user may decide: *“now I want to go to the train station”* or *“I don’t want to meet with Sam, I now want to meet with the Prince”*. This approach will result in a higher level of control over the environment, avoids one-sided dialogues and make the system more adjustable to the user’s preferences.

6.2.3. TOWARDS LOGGING USERS’ ACTIVITIES

As mentioned during the last prototype evaluation, it is highly important for every expert user to ensure that the process of using the system by his target users is recorded, and they can further use this data for further analysis. Considering the importance of this requirement for experts’ studies, the current version of VENECA includes an integrated screen capturing mechanism, which allows the recording of the whole playing process into video files. This screen capturing program is launched automatically when the game starts, which means that future experts do not have to worry about launching the separate program on time. The shortcoming of such an approach is that it requires distribution of separate software along with VENECA. The idea of implementing a self screen capturing mechanism that would be integrated into game does not seem possible at the moment, considering the limitations of the Blender environment and its orientation for modelling purposes. However, there are possible alternative directions for achieving the logging result.

6.2.3.1. Video recording

Video recording is an older, but still effective approach for recording users’ actions. Moreover, this method is irreplaceable if experts are not only interested in recording all the events, that are happening on the screen, but also wish to analyse the target users’ reactions to particular game events. Screen-capturing features cannot provide this information. Moreover, videotaping is less costly, because it will make the logging process independent from the program and reduce the memory cost of VENECA. When the camera is placed at

the optimal distance from the screen and the child user, experts may achieve a full log of both screen events and child's comprehension, feelings and reactions to these events.

6.2.3.2. Keeping a log of pre-defined events

While the implementation of a screen capturing mechanism inside VENECA does not seem possible, it is possible to define a set of game events and measures that, from the experts' point of view, would be important for their further analysis. One of the possible features that could be interesting for experts is playing time. Predicting the importance of this measure for experts, a highly precise timer was already integrated into VENECA and made invisible for the first version. If future developers discover the importance of such a measure, the only modification that they would require, is to make the timer visible. Additionally, the algorithm used in VENECA could be modified so that the program would count the number of particular events. For example, it might be interesting for the experts to know how much time passes before the users obey traffic constraints again after the warning message is already presented. For the lately implemented "recall the task" button, it would be interesting for the experts to analyse, how much time passes before users need to recall the task and how often they use this game feature. Particular sensors for locations may be introduced in order to analyze, how often the user chooses the shortest possible way for the target location and how often they select the longer path. All this information could be analysed by screen capturing and videotaping. However, it wouldn't allow such a high degree of correctness in terms of time, and would require more effort for experts in analyzing these features.

6.2.3.3. Sensors

Depending on the experts' requirements, it might be important for them to keep a log of all the eye fixations and head movements of the user. For example, the experts may want to analyze how often the visual icons grab the user's attention during the road crossing task, or what the user's points of fixation are during social rewards. This last evidence could be very important for analysis of fixation patterns for the highly believable virtual characters versus the patterns, reported for people (recall experiment by Klin et al., 2002a, 2002b). Another interesting question is how often the users fixate on the sidebar element with black-and-white icons in order to recall the future directions versus how often they fixate on the visual cues near the buildings. Videotaping, screen capturing and events' logging techniques are not able to provide this data for the experts.

6.3.1.4. Which direction is optimal?

Analysis of advantages of all possible logging techniques suggests that there is no obvious “optimal” decision. Each of the suggested methods could be useful, depending on the purposes of the experts. While the existing screen capturing mechanism guarantees recording of the screen events, it is costly in terms of additional memory and it cannot record information about users’ emotional reaction to particular events. Neither does it provide information about fixation points of the user. While the videotaping technique allows recording of both the user’s emotional responses and screen events, and economizes the memory, it is at the same time costly because it requires additional recording devices and does not lend itself to automatic recording. While the log of particular events allows the experts to concentrate on necessary features and calculate time and distance parameters more precisely, it may also cost additional memory. Furthermore, it limits the variety of recording features and does not provide any information about users’ reactions and fixations. While sensors provide valuable information that cannot be logged by means of the previous techniques, they don’t provide a log of screen events and users’ emotional responses.

By analyzing the obvious advantages of each of these methods, it can be concluded that neither can be considered the optimal one. The usability of each logging method is highly dependent on the experts’ purposes. It is likely that, only a combinations of all these logging techniques would provide experts with the highest and optimal mechanism that would record the screen events as well as the users’ emotional reactions, keep a log of different pre-defined events, and record the fixation points of the users.

6.2.4. HCI. TOWARDS INCREASED INTELLIGENCE

As was already mentioned, the first version of VENECA does not support flexibility in dialogues between the user and the program. This could be partially avoided in the future by means of personalisation techniques described in section 6.2.2. An additional extension that would suggest even more flexibility is related to the artificial behaviour of the system. Andy, as a main character has some artificial features included: for example, he has sensors that react when the location is reached. For the social warnings, these sensors detect the light of the traffic light and process the information about current location and intelligently make Andy to turn back and warn the user. However, this intelligence in Andy’s behaviour could be increased. This can be done by integrating the natural language

processing module into VENECA. In this case, the user could contact with Andy not only by means of keyboard, but also verbally. If Andy could process users' verbal responses and generate a response that could be artificial enough, this could be a good communicative training for final target users. Additionally, analogous techniques could be implemented for the remaining characters. Instead of watching the Prince speaking, it would be more believable for the user to talk to the Prince character, or, when Andy comes closer to the man on the road, it would be more natural, if the user could verbally ask: "*How do I reach the train station?*" rather than clicking on the question sign. When reaching Sam, the user could verbally call him, instead of pressing the door bell.

The intelligence of the game could also be increased is navigation: instead of using the keyboard, it may be extremely effective to use the information of the eye-tracking add-in, and automatically rotate the camera in the direction the user is looking. The game characters could also benefit from this eye-tracking add-in by means of looking at the points of the users' fixations. This technique would suggest a very valuable possibility of simulating developmental responses, mentioned in Chapter 2 as one of the suggestions of Charman & Stone (2006).

6.2.5. 2D MODES. TOWARDS HIGHER FLEXIBILITY

During the design process, it was decided that the 2D modes do not allow for variation of navigation speed, because it is presented by means of rendered pictures of the scene. However, it is possible to simulate different levels of speed in 2D modes. In order to do this, the rendered pictures must be made not only for the frontal view of the street, but also for the different levels of depth for the same frontal view. Following this, the navigation speed can be simulated by means of the following design: for the slower speed, the depth of street view will be changed more slowly (a larger number of rendered images of different depth will be required), while for the faster navigation speed, the depth will be presented in a less detailed way. In addition to making the navigation speed flexible for all the modes of believability, this approach will also allow simulation of 3D navigation in a 2D mode, an absolutely novel design decision. Moreover, it will allow activation of all the navigation keys in the 2D mode rather than just moving left and right.

6.2.6. TOWARDS MAP READING SUPPORT

Two out of three experts who took part in prototype testings, mentioned that it might be useful to include a map on the highest levels of the game. Taking into account the visual processing skills of users with ASC, this suggestion may provide good visual support for the final target users. As suggested during the last evaluation, such maps could be delivered in a printed static form. However, it would definitely be useful to create a real-time map, with the upper view of the scene that would display the target locations and the user's current position, as is done in modern navigators. In order to implement this, the following steps may be taken by future developers:

- 1) A full copy of an existing scene must be made;
- 2) A camera must be aligned to the upper view of the scene;
- 3) All peripheral objects must be removed from the scene, and all the textures replaced with plain colours in order to simplify the scene. All the traffic elements and the cars must also be removed;
- 4) The main character must be replaced with a large, visible, red pointer;
- 5) The target location must be marked by pointers;
- 6) A scene must be placed as an “overlapping background” on the main scene.

These steps will allow the implementation of a fully real-time navigator which will display all the character's movements in space. However, before using this map element in studies with children, it is important to ensure that such an active additional element will not decrease the overall attention of users and make the FOV too overlapped. Additional non-trivial decisions may be required in order not to sacrifice the running speed, because a map element would require additional graphical processing capacities.

6.2.7 PROFILES. TOWARDS MONITORING SUPPORT

When the researchers want to use the tool for educative purposes and monitor the improvements of participants, it could be useful for them to have the profiles of users that can be automatically edited with required information after each session. Moreover, where the logging mechanism and personalisation extensions to be implemented, such profiles would suggest to researchers information about the personal preferences of users (such as requires navigation speed, enjoyable rewards, characters and locations) and their progress

in particular aspects (the number of fixations on the traffic light could suggest increased attention, and decreased playing time could suggest better orientation in space). Moreover, for the more flexible believability levels, this information would be very important in order to answer the question concerning the optimal comprehensive level.

6.2.8. TOWARDS INCREASED RUNNING SPEED

When discussing technical capacities, the tool still remains insufficiently optimized. Technical decisions, such as avoiding unnecessary animations and stopping traffic when social rewards are delivered, and creating the lists with frames are not enough when the game runs in full screen mode, and occasionally various delays may happen after characters' animations. Therefore, the algorithms used in VENECA can be further optimized. For example, currently, the game runs with respect to the higher frame rate rather than the quality, and the difference in the quality of animations is not visible even in the full screen mode. Further simplification of frames per second will probably lead to higher running speed on non-specific hardware.

6.2.9 FUTURE EVALUATION WITH RESEARCH USERS

The design process, covered in this project, includes three evaluation sessions. Because of the limited number of experts, the feedback gained during these evaluation steps was more oriented on qualitative data. As long the design decisions were still being analysed, it was important to gain as much valuable information as possible. For this purpose, all the questions had an open-ended format, and semi-structured interviews were used. While these sessions were sufficient for making design decisions, more detailed evaluation is needed in order to make final conclusions about the usability of the game by experts. Taking into account that in the first two evaluation sessions, incomplete prototypes were presented, it is very important to evaluate the completed first version of VENECA with a larger number of experts in the future. This future research will help to ensure that all the experts observe an equal set of features. The latter aspect is very important for making the results more comparable with each other.

When analyzing usability of the tool, it is more appropriate to talk about qualitative rather than quantitative data. However, if quantitative information will be needed, evaluation with a larger number of research experts will produce this kind of data. Statistical analyses were not launched in this project due to the limited number of expert participants and time, and

due to the inappropriateness to the evaluation purposes of this project. However, if future research studies involved a sufficient number of experts, more detailed statistical analyses, such as ANOVA, may be launched. However, in order to make statistical analysis of usability, the evaluation steps will require modification. For this purpose, the qualitative open-ended interviews need to be substituted with structured questionnaires. Such questionnaires will allow researchers to gain the experts' feedback on the same feature, and using the same set of limited answers. The optimal way of designing such quantitative questionnaires is to make them scalar. Scalar questions usually contain two opposite opinions and provide a scale between them, for example: *"agree 0-1-2-3-4-5 disagree"*. This quantitative data will be very useful for statistical analysis. For example, it may be essential to analyse the average mark (usually referred to as "mean" in statistical studies), given by experts to the intensiveness of colours. Another question may investigate the scale value that was used by the majority of experts when specifying their opinion about colours (usually referred to as "mode"). Another way of acquiring quantitative data is to use lists of comparable features and ask experts to rank elements of these lists.

Moreover, if more experts are involved, the usability of the experts' interface may also be qualitatively evaluated by means of different "during using" techniques (see Dix et al, 2004 pp 343-362). Such techniques suppose observation of users exploring the system. In future evaluations, the experts may be given a control panel and asked to set a particular study. During this task, different criteria, such as setting time, or number of errors may be used for quantitative analysis.

All these techniques will allow a more detailed analysis of every feature, supported by statistical feedback from target users. However, this direction of evaluation still remains "theoretical" for the game element. Even the authoritative experts provide their feedback based on their hypothetical ideas, experience in the field and subjective feelings. Many of such opinions may not be supported by the actual behaviour of child users, especially for the novel, non-explored hypotheses. Therefore, in order to answer all these questions precisely and objectively, experts may need to observe the use of this tool by their target users, children with ASC. This will be discussed in the following section.

6.2.10 FUTURE EVALUATION WITH CHILDREN WITH ASC

As mentioned, experts may require detailed evaluation of the game element with child users, in order to justify their hypothetical ideas with empirical evidence. Such evaluation steps were not taken in this project due to several limitations. The main limitation refers to the access to the target group of child users. In order to get reliable feedback, it is important to involve sufficient number of participants that would not only be individuals with ASC, but also fall into the target age interval (9-14 years old). It was initially analysed that the access to the users from this group may be problematic.

Another important question that must be considered by future research experts is what techniques and parameters to use in order to answer initial questions. There exist two possible groups of results that may be interesting for researchers: the process of playing the game and the post-playing effect. Some of the techniques that may be used in order to analyse the game playing process, were discussed in section 6.2.3, when analyzing different logging techniques. However, is this data sufficient in order to answer all potential research questions? In order to find out the optimal balance between comprehension and generalization, the experts will require both types of information: during playing (in order to analyse comprehension) and post-playing (in order to analyse the generalization effect). While the “during using” data can be easily recorded, the post-using effect requires much more detailed analysis. The latter analysis refers to monitoring. Monitoring is a long process of observing the same user in the real-world task before and after using the software. For example, when analysing the road crossing software, used by Josman et al (2008), it was highlighted that the study has a high reliance because the authors not only observed the playing process, but also included the monitoring stage. Such a stage is in most cases time-costly, and may require several months to observe the child’s behavioural changes. Unfortunately, the time limitations of the project and the amount of design work to be done, even hypothetically did not assume such monitoring-based evaluations. However, this evidence may be of high importance for future research experts.

CHAPTER 7

CONCLUSIONS

At the end of this project, it is possible to conclude that the first version of VENECA provides a high degree of flexibility and support to investigate a full scope of questions, as mentioned at the beginning of the thesis. The design process of VENECA was organized in a traditional waterfall style, which allowed very detailed analysis of different design decisions. The initial pre-design steps resulted in some very important decisions concerning the environment for implementation and programming language, suggested the target age of final users, and allowed precise specification of functional and user requirements. Moreover, the decision to add the KBTA method to the HTA technique for the game element allowed consideration of different usability factors that were highly important for the design stage, for example, the inclusion of visual support into text instruction. Moreover, an additional timer-based tool which was implemented in order to adjust an appropriate speech speed of the TTS system, provided a high degree of effectiveness and precision in adjusting the system's verbal messages to the needs of the final target users. The decision to follow the iterative design strategy was also very useful, because between particular iterations, very useful suggestions from the target users of VENECA, research experts, were taken into account. Re-design of these features at the later stages of implementation would be very costly. During the final prototype evaluation, it was possible to present the completed version of VENECA with a full set of features included, and, therefore, obtain more detailed feedback about the system's usability. Suggestions of the last expert about making the game features descriptions more objective, providing the logging mechanism and including the task recalling feature, were considered and changed during the final implementation step. Moreover, in the best traditions of software design, implementation of the manual materials, guidelines and licence for the software makes VENECA a complete, finished tool that can be distributed for different needs with all required materials.

To sum up the overall importance of the game's features, VENECA combines a set of very useful and interconnected features that are able to investigate potentially interesting and novel hypotheses. Experts did experience no difficulties during any of the prototype testings when analyzing and specifying possible studies. During the last evaluation, the expert Dr G.R., also highlighted the importance of comparison of ecological validity, tasks

representation and social tasks, as well as the overall logic of using the navigation task in the multitasking environment, which suggests that the initial set of hypotheses and game features of VENECA may potentially be of high interest to the target group of this project: research experts. The detailed design process and discussion of design decisions with experts during the whole developmental process, as well as the usability questionnaire for the game element, presented in table 3, also suggests that there are no major problems that would prevent the usability of the game by the experts' target group, children with ASC.

At the end of this thesis all possible extensions and improvements of VENECA were analyzed both in terms of various interesting directions, difficulties that can be met and comparability of effectiveness of different directions within the same extension. This information can serve as a very useful guide for possible future developers of VENECA. Implementation of a fully flexible scene and switching the believability question to experts is a very promising direction in terms of the highest possible flexibility. This approach could make VENECA a universal tool for building a large variety of environments. The idea of increasing a level of personalisation, implementation of users' profiles, introducing alternative logging techniques and making the game's behaviour more artificial, will allow much more information to be gained about the final users, and involve them in a bi-directional interactive process with the system. The map feature could also result in an interesting research question about map reading skills in children with ASC. It is believed that the implementation of all these extensions in the future will allow VENECA to cover an even wider scope of all the questions existing in the area and become more flexible and universal.

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